Testing and Evaluation of Automotive Propane Conversion Equipment: 1

L. Segal
Engine Research and Development Laboratory
Department of Mechanical Engineering
University of Toronto

Submitted to the
Ministry of Transportation and Communications
Automotive Energy Group

Published by:
The Transportation Energy Management Program (TEMP)
Policy Planning and Research Division
Ontario Ministry of Transportation and Communications
Hon. James W. Snow, Minister
H.F. Gilbert, Deputy Minister

Ontario Ministry of Energy
Hon. Robert Welch, Minister
G.R. Thompson, Deputy Minister

Published without prejudice
as to the application of the findings.
Crown copyright reserved; however, this
document may be reproduced for non-commercial
purposes with attribution to the Government of Ontario

For additional copies write:
The Editor
Research and Development Branch
Ministry of Transportation and Communications
1201 Wilson Avenue
Downsview, Ontario
M3M 1J8
February 1982

TABLE OF CONTENTS

1. Summary

3. Characteristics of Test Installation

   3.1 Test Engine

   3.2 Test Equipment

4. Description of Tested Propane Carburetion Systems

5. Test Procedure

6. Test Results

7. Optimization of IMPCO Carburetion System on GM V6 Code K Engine

8. Conclusions

9. Proposal for Future Work

Appendix 1 - Calculations for Corrected Parameters

Appendix 2 - Calculation of Air-Fuel Ratio from Exhaust Gas Constituents

Appendix 3 - Classification of Tested Propane Carburetion Systems

1/ SUMMARY

This compiles all the data on the comparative tests of eight propane carburetion systems on a GM V6 229 CID code K-1980 engine.

The results for power, fuel economy and emissions are compared with the baseline data obtained on the same engine operating on gasoline.

Equipped with propane carburetion, the engine can develop the same power as with gasoline, with an increase of 5% to 10% at low speeds.

The energy efficiency can be improved by 5% to 15%, depending on load and speed. Because propane is about 30% lighter than gasoline, in volume terms the use of propane still results in a 5% to 25% increase in fuel consumption. Despite the increase in volu-metric consumption, an appreciable economic advantage can result if propane price is realistically established in comparison with gasoline for an equivalent energy content.

For the tested systems the emissions are higher on propane, with the exception of carbon monoxide for a few systems at full load (before Catalytic converter; gasoline carburetion with all emission control equipment operational, propane carburetion without).

The exhaust temperatures for propane are higher at full load and lower at partial loads. During the test, the engine ran satisfactorily, and at the end of the 250 hr. program is in sound mechanical condition.

The general classification of tested propane carburetion systems is: IMPCO, CENTURY, ALGAS, BEAM and ALTERNATIVE FUEL SYSTEMS, CONVERSION FUEL SYSTEMS, FUELCON and C. K. PROPANE.

The large spread in the fuel economy and emissions results is determined by the quality and the level of engineering development of the carburetion systems. The use of the best available systems and further development work for new systems optimized on specific engine models will improve considerably the overall fuel economy, emissions level and performance in fleet applications.

3. CHARACTERISTICS OF TEST INSTALLATION

3.1 Test Engine

Make: General Motors - Chevrolet Division

Model: Code K, V-90°

Number of cylinders: 6

Serial number: D9M 1810 4792428

Bore: 85.750 mm (3.376 in)

Stroke: 88.392 mm (3.480 in)

Displacement: 3.8 ℓ (229 CID)

Compression ratio: 8.6:1

Carburetor: Rochester - "Dualjet 210" 17080170

Air filter: AC - A 178C

Distributor: Delco-Remy HEI 1110756

Vacuum advance: 694-24; 520707 max. advance 16° at 7.5 in.Hg.

Mechanical advance: 2° at 1550 rpm
9° at 2400 rpm
14° at 4100 rpm

Spark plugs: AC -R 45 TS
gap .045 in

Firing order: 1-6-5-4-3-2

Emissions control system - Fig.3.1-1 unmodified original arrangment on the Pontiac - Le Mans 1980 car in which the engine was mounted. The original catalytic converter and muffler are retained - Fig. 3.2-2.

Electrical system - Fig.3.1-2, designed for engine dynamometer testing

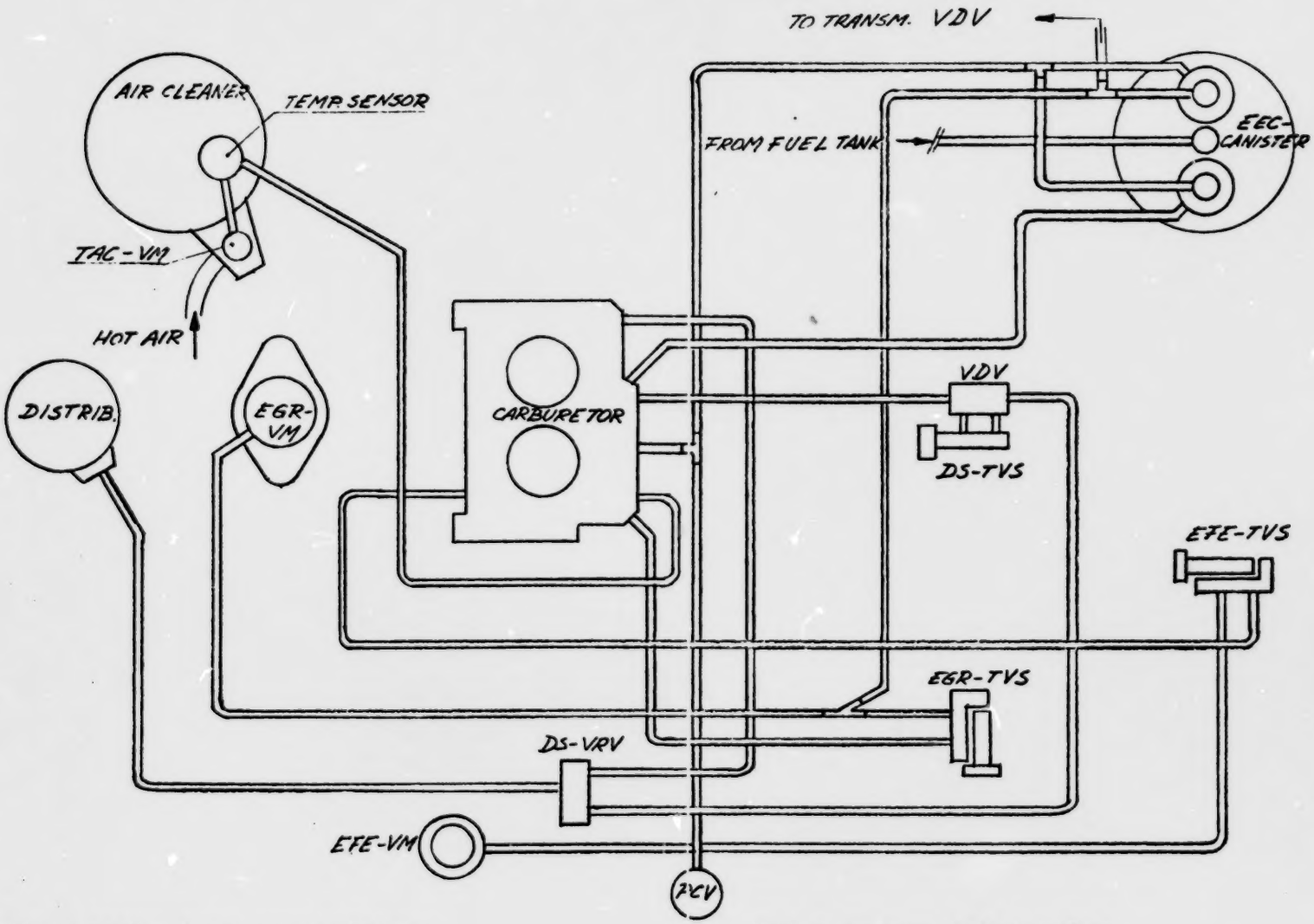
Generator: Delco-Remy model 10-SI

Fan: fixed blades, part no. 1243562

Mechanical coupling with the dynamometer:

- flywheel: part no. 366860
- complete clutch: part no. 14007393 plate
  471576 cover and spring
- bellhousing: part no. 462606

Engine support: 3 points (2 for engine, 1 for dynamometer, with original rubber vibration dampers), ensuring the horizontal position of the carburetor mounting surface on the intake manifold.



EFE = early fuel evaporation
EGR = exhaust gas recirculation
PCV = positive crankcase ventilation
EEC = evaporative emission control
TAC = thermostatic air cleaner

VDV = vacuum delay valve
VRV = vacuum regulator valve
TVS = thermal vacuum switch
VM = vacuum motor
DS = distributor spark

Fig. 3.1-1: Emissions control system for gasoline

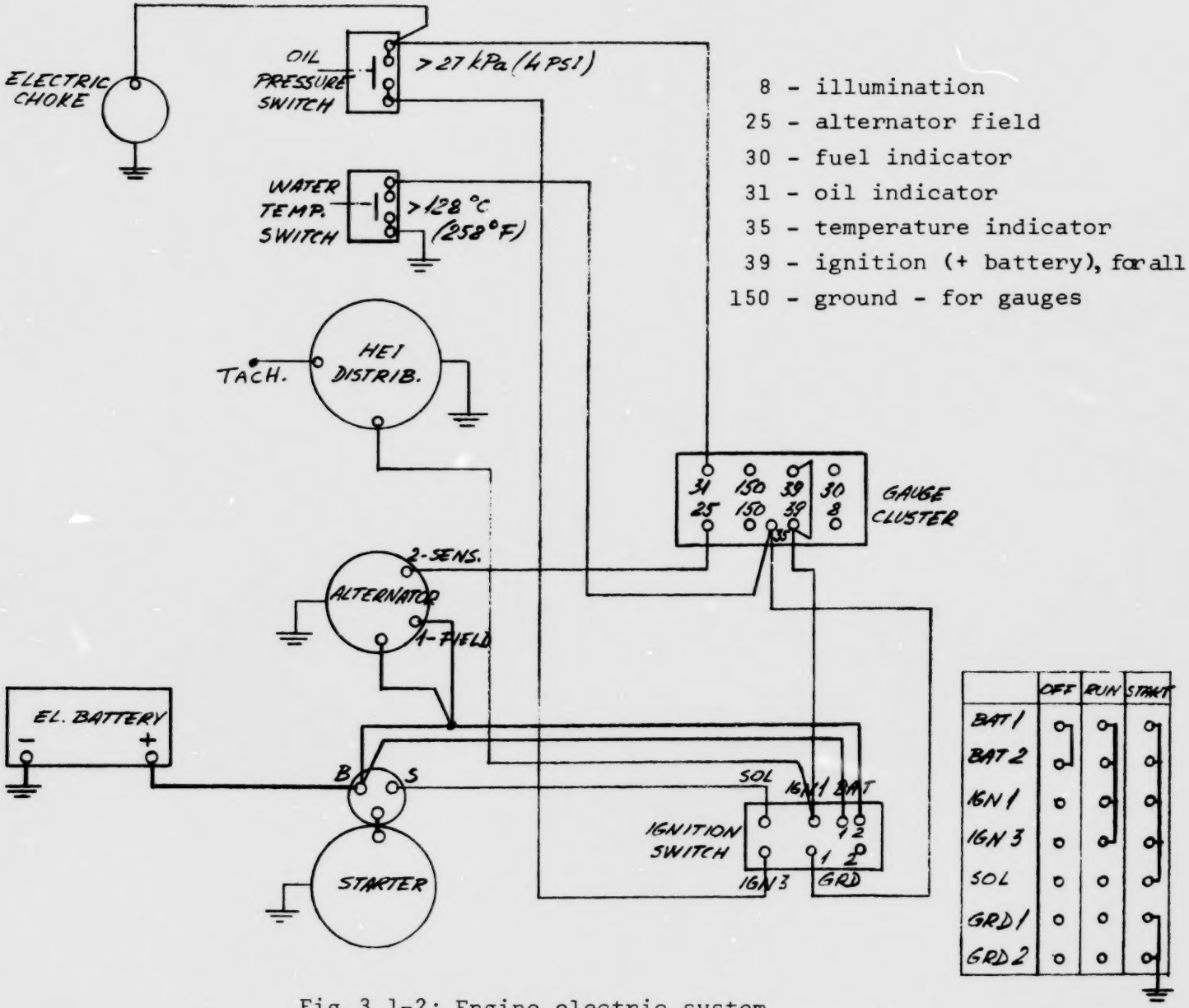


Fig. 3.1-2: Engine electric system
for dynaniometer application

3.2 TEST EQUIPMENT

The characteristics determining the precision of measurement are listed below:

3.2.1 Dynamometer: 'Go-power'model 557 B, momentum exchange water brake.

Load control: water valve, controlling the filling of the dynamometer body.

Maximum speed, torque and horsepower given in Fig. 3.2-1.

3.2.1.1. Dynamometer stator reaction force measuring system: electric strain-gauge load cell, actuated through a rod with self-aligning bearings.

Load cell: 'Interface'- 'Sealed Super-Mini', model SSM-1000 (1000 lb. range)

Non - linearity: $\pm$ 0.05% rated output

Hysteresis: $\pm$ 0.03% rated output

Non-repeatability: $\pm$ 0.02% rated output

Compensated temperature range: 0-150°F

Temperature effect on zero or rated output:

$\pm$ 0.08% rated output/100°F

3.2.1.2. Calibration arm

Length: 2 ft.

Torque loading: 4.7 lb. ft.

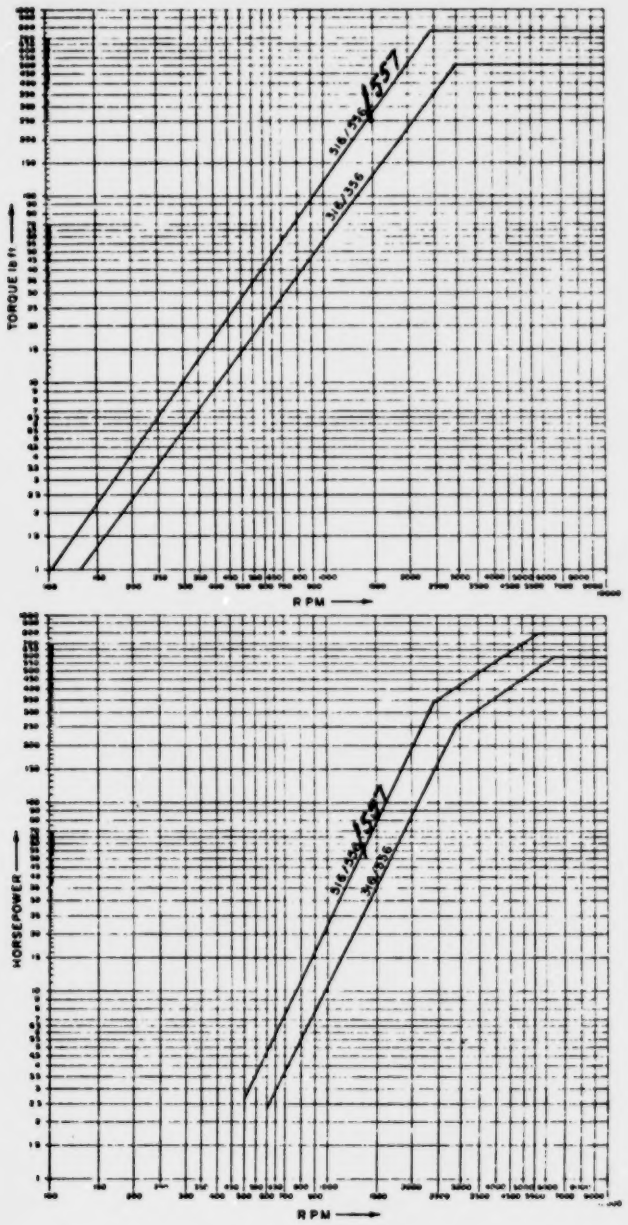


Fig. 3.2-1:'Go-power'model 557 B dynamometer loading capacity

3.2.1.3 Calibration weight: 62.5891 lb.
Total calibration reading: 129.88 lb. ft.
Average electric calibration reading: 108.37 lb. ft.
Sensitivity: 0.04% FS
Full range setting: 199.99 lb. ft.

3.2.1.4 Dynamometer speed transducer: 60 teeth gear and magnetic pick-up, 1 Hz/1 rpm.

3.2.2 Load cell indicator: 'Lebow' model 7540
Excitation: regulated 5V, 3.28 kHz
Nonlinearity: ± 0.005% FS
Temperature effect: 0.15% FS/100°F
Digital display - resolution: 1 part in 10,000
- accuracy: ± 1 count
- linearity: ± 0.005% FS
- stability: 0.15% FS/100°F

3.2.3 Speed indicator: 'Fluke' model 1950 A Digital Counter
Accuracy: ± 2 counts

3.2.4 Servo controlled throttle actuator system: 'Labeco' model 304. Angular position control and indication, adjustable for zero and WOT position of the carburetor shaft (indication 0 to 1000).

3.2.5 Balance for fuel consumption measurement: 'Mettler' model PK 36
Range: 0-30,000 g
Readability: 1 g (0.1 g up to 6,000 g, in the 'Delta Range')

Reproducibility: < 0.5 g (< 0.1 g in 'Delta Range')

Linearity: ± 1 g (± 0.1 g in Delta Range)

Temperature range: 0-40°C

3.2.6 Temperature measurement (I stage of project):

Thermoelectric thermocouple indicator, on J calibration range (-200 to 930°C)

Accuracy: ± 1°C

3.2.7 $HC/CO/CO_2$ emissions analyzer: 'Horiba' model Mexa - 400

Measuring method: non-dispersive infrared

Ranges: 0-250 and 0-1000 ppm HC (n-hexane equivalent)

0-2 and 0-10% CO

0-16% CO_2

Repeatability: ± 5% FS

Response time: 90% of reading in 7 seconds

Calibration gas mixture: 806 ± 16 ppm HC

4.67 ± 0.09% CO

4.61 ± 0.09% CO_2

3.2.8 NO/NO_x emission analyzer: 'Beckman' model 951

Measuring method: chemiluminiscence.

Ranges: 0-10, 0-25, 0-100, 0-250, 0-1000, 0-2500 and 0-10,000 ppm.

Sensitivity: 0.1 ppm on 10 ppm range.

Linearity: ± 1% FS

Precision: 0.5% FS

Dynamic response: ≤ 1s (≤ 3s on 10 ppm range)

Calibration gas: 1165 ± 24 ppm NO, 1.7 ppm NO_2

3.2.9 O_2 emission analyzer: 'Teledyne Analytical Instruments'Model 320 P-4

Measuring method: Micro-fuel cell

Ranges: 0-5, 0-10, 0-25% O_2

Sensitivity: ±0-5% FS

Accuracy: ±1% FS

Response time: 90% in less than 5s

The schematics of the emissions analysis is presented in Fig. 3.2-2.

3.2.10 Temperature measurement: 'Doric Trendicator'series 400 A and 'Hy - Cal Eng.'Thermocouples,

Thermocouple range: E (Chromel-Constantan),

Range: -450 to + 1600°F

Accuracy: ±1°F

Junction: grounded

Sheath: 316 Stainless Steel, .125 dia.

3.2.11 Knock sensor: 'Bruel & Kjaer'piezoelectric accelerometer model 4368 with charge amplifier, 3kHz high-pass filter and headphones.

Accelerometer frequency range: 0.2-9.00 kHz (10%)

Maximum accelerometer ambient temperature: 250°C

3.2.12 Engine analyzer -'Sun'model EET - 1120

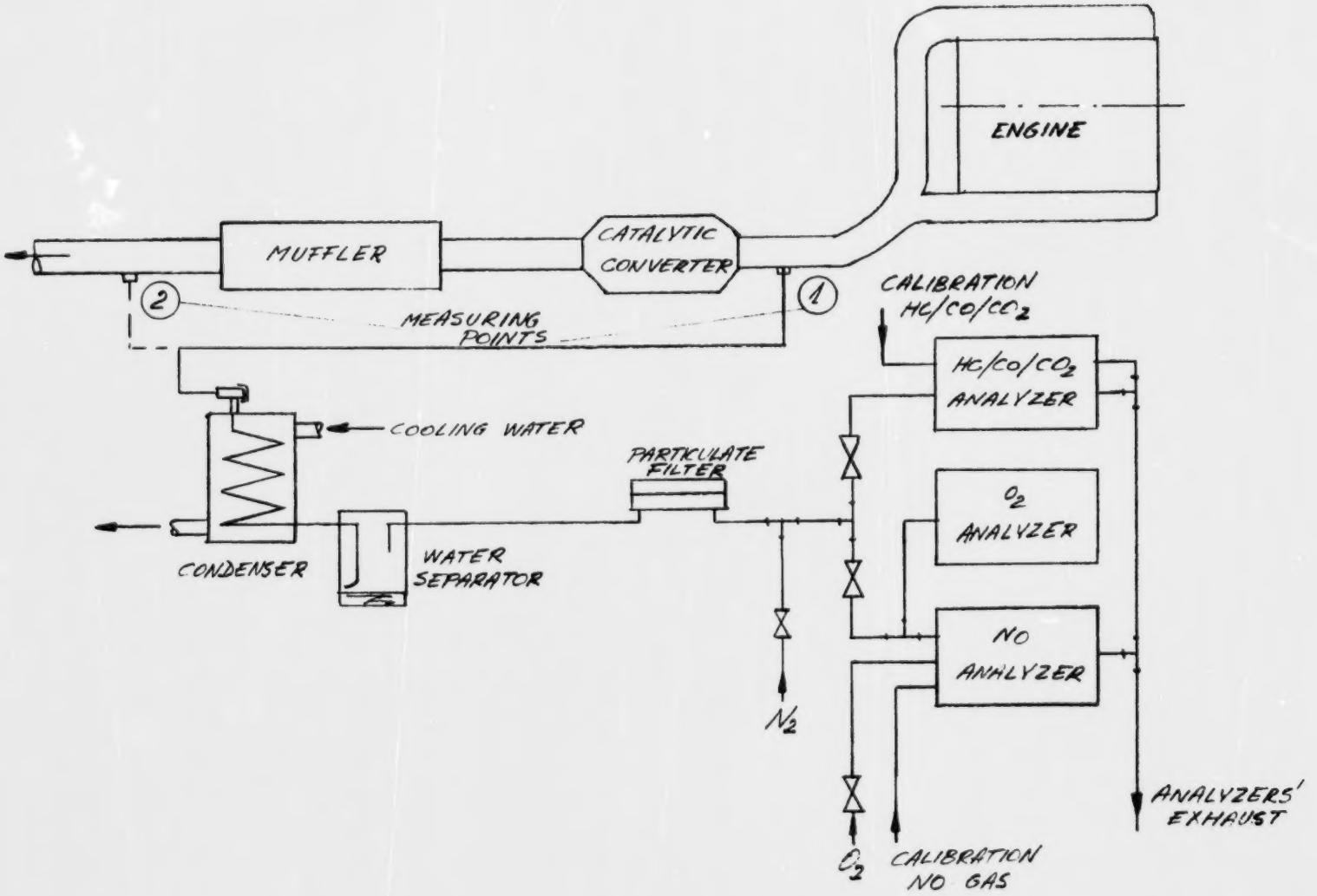


Figure 3.2-2: Emissions analytical train schematics

3.2.13 Engine and dynamometer monitoring gages:

Engine water temperature

Engine oil pressure

Battery charge

Dynamometer water temperature are standard automotive gages.

3.2.14 Barometric pressure: mercury barometer 'Eberbach', 0.01 in. divisions.

3.2.15 Ambient temperature: mercury thermometer 'Weksler', 1°F divisions.

3.2.16 Water vapour pressure in atmosphere: sling-psychrometer.

3.2.17 Exhaust manifolds and pipes cooling fan: 5 HP, electrically driven axial fan.

4. DESCRIPTION OF TESTED CARBURETION SYSTEMS

All the propane mixers tested in this project are mounted on top of the gasoline carburetor except IMPCO, which has its own carburetor body. The original throttle system is retained for the systems using the gasoline carburetor, with the choke throttle plates blocked in the open position.

Data on specific carburetion systems including the principle of operation are presented in Table 4-1.

The schematic views of the carburetion systems are presented in Figures 4-1 to 4-6.

Because of the complexity of installation of the IMPCO carburetion system equipped with EC 1 emission control device, the layout of this system is presented in Figure 4-7. Other systems have only the fuel supply between vaporizer/regulator and mixer, the heating water supply and a manifold vacuum line for economizer, if installed. For the systems with electric fuelock, the electrovalve is activated when the ignition key is turned on.

Table 4-1: Technical data on propane carburetion systems

CARBURETION SYSTEM	VAPORIZER/REGULATOR		MIXER		COMMENTS
	Stages	Model	Principle	Model	
BEAM	2	450B	Venturi	51C-19-42	Venturi: 310A-42 metering plate: 6C-261-250
A.F.S.	3	Tartarini (Italy) RP/77 SUPER	flow nozzle	UM - 2	
ALGAS	1	C-250 A4	Air valve	500A, 2175	
CENTURY	2	M6,2504-A	Air valve	ACUCARB	Rectangular air valves
C.F.S.	2	Not specified (approx. IMPCO)	Air valve	Not specified (approx. ALGAS)	
FUELCON	2	Not specified (approx. IMPCO)	Air valve	Not specified (approx. ALGAS	
C.K.	2	C.K.	2 flow nozzles	Not specified	The mixer is mounted inside the original filter
IMPCO	2	E with EC 1	Air valve	CA 125	-carburetor diaphragm: L (lean) -vaporizer secondary spring: silver

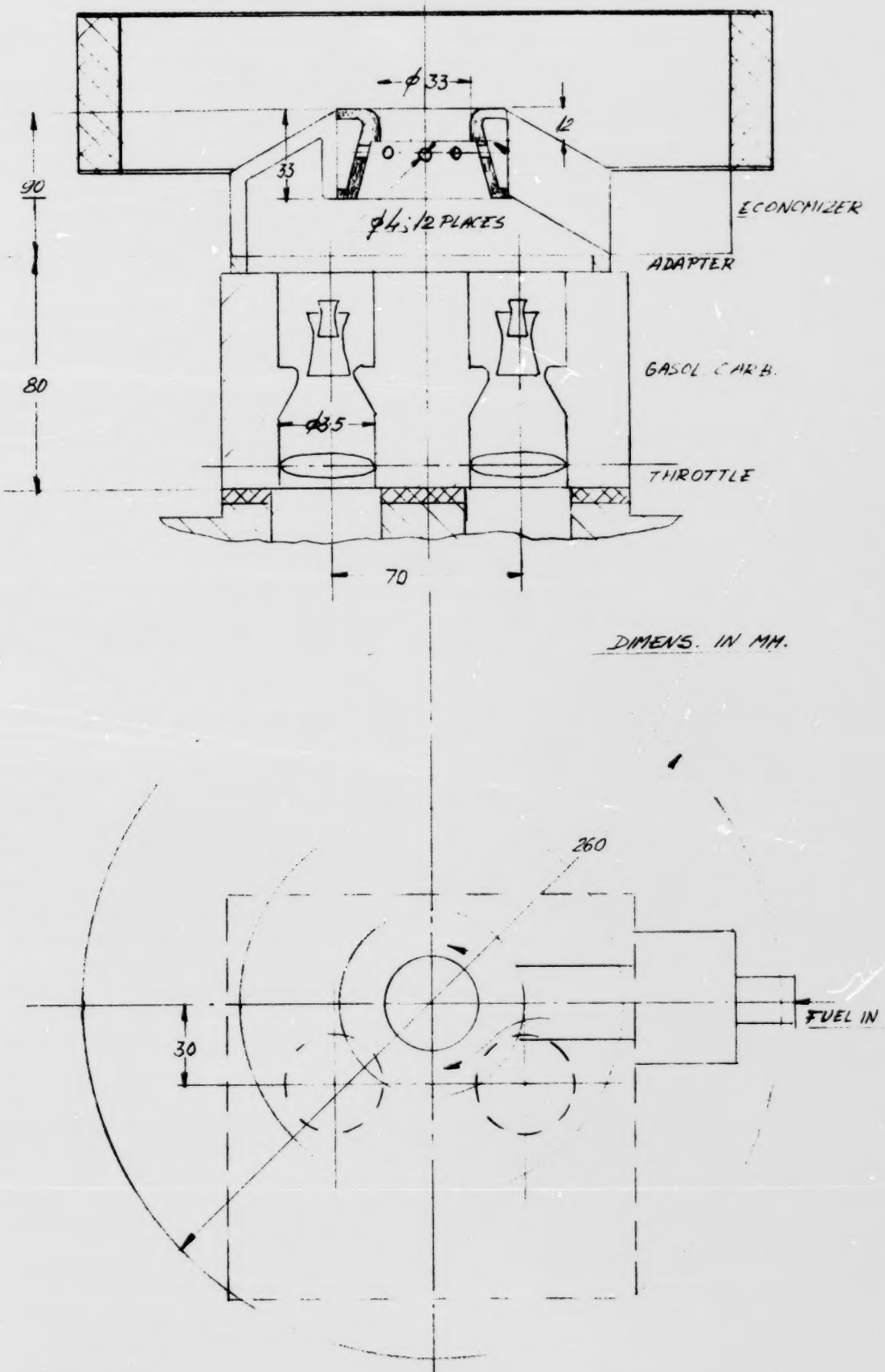


Figure 4-1: Schematic view of BEAM 51C-19-42-propane carburetion system mounted on top of gasoline carburetor

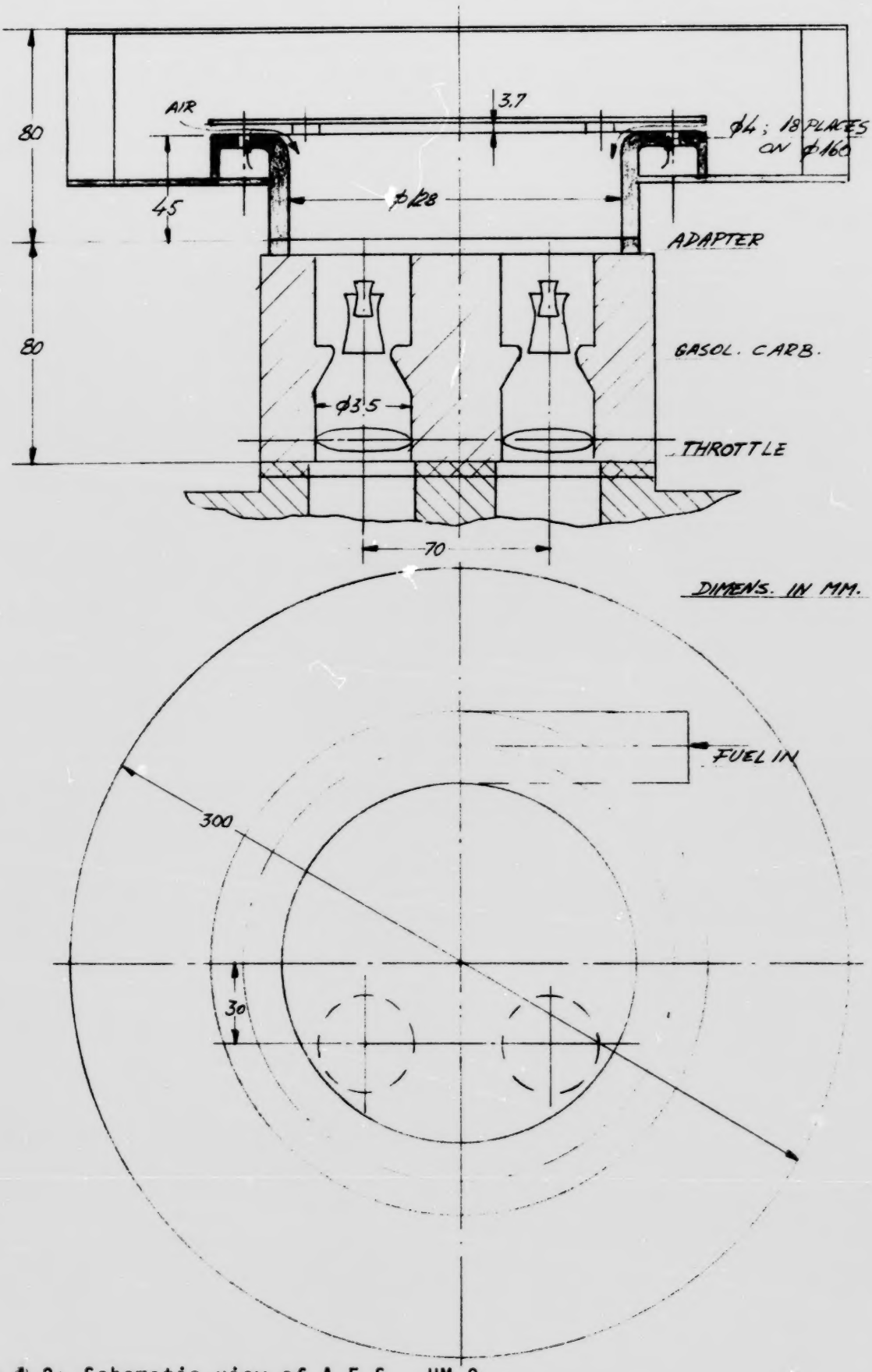


Figure 4-2: Schematic view of A.F.S. UM-2 propane carburetion system mounted on top of gasoline carburetor

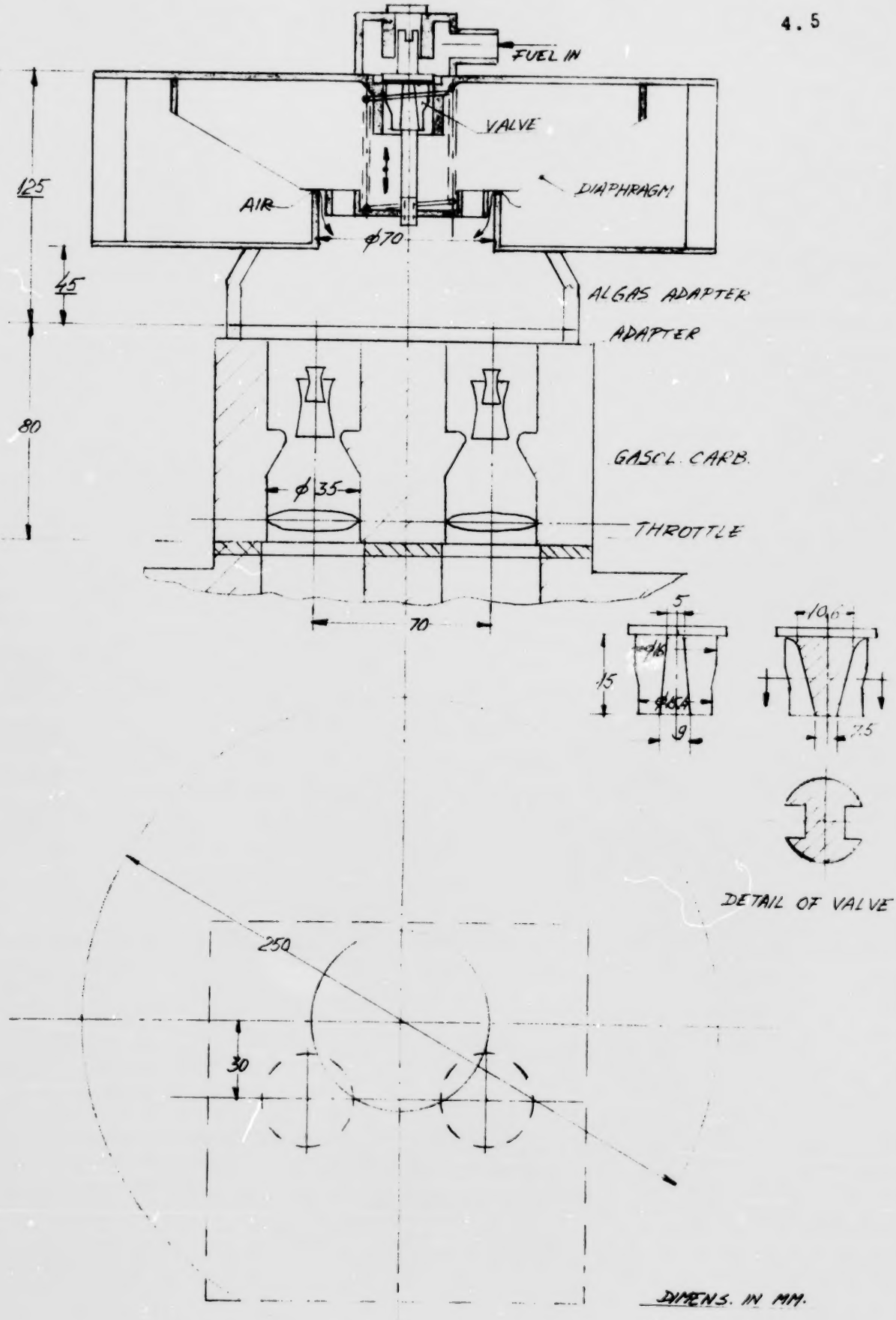


Figure 4-3: Schematic view of Algas 500 A, 2175 propane carburetion system mounted on top of gasoline carburetor

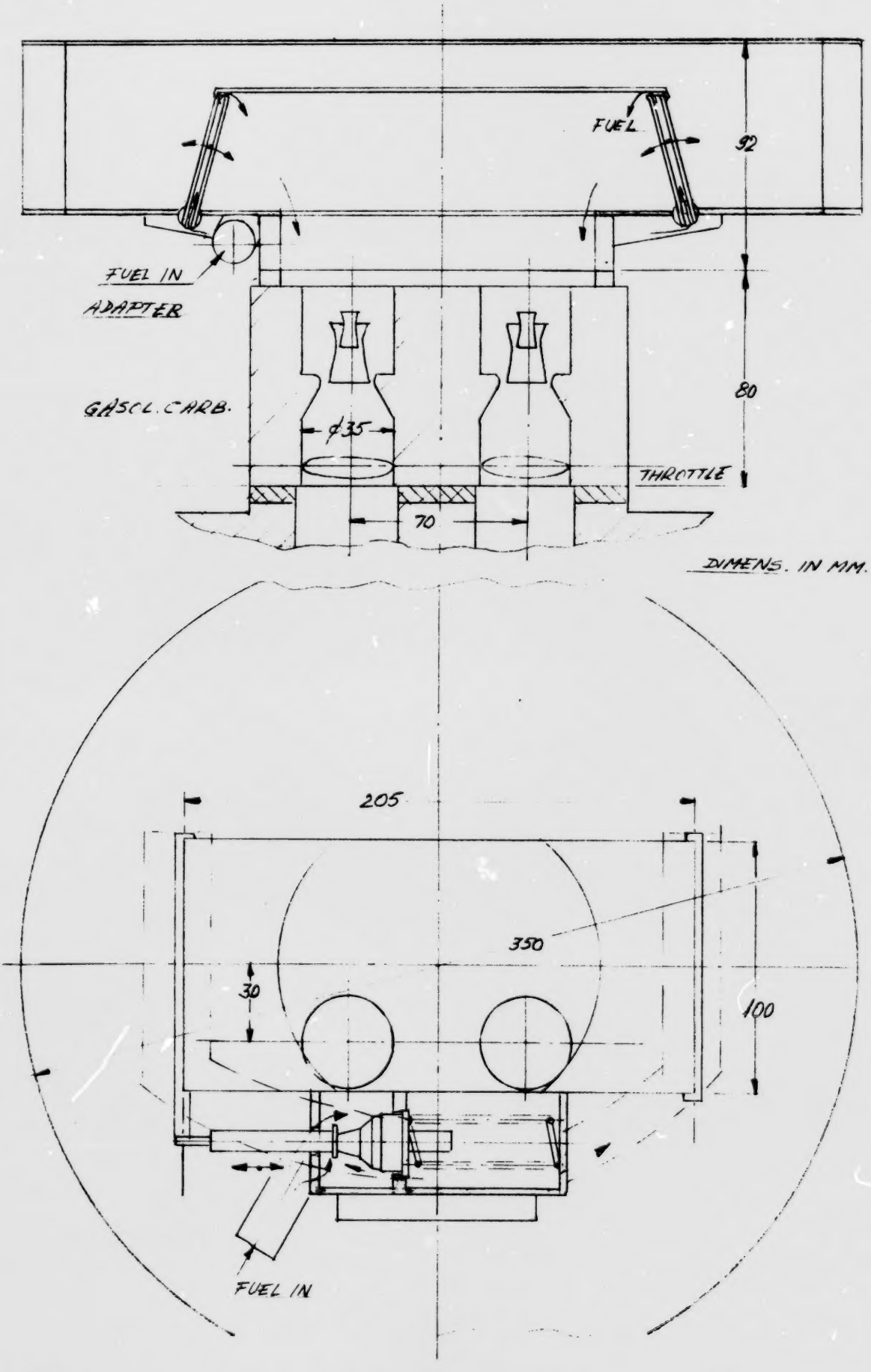


Figure 4-4: Schematic view of Century 'Acucarb' propane carburetion system mounted

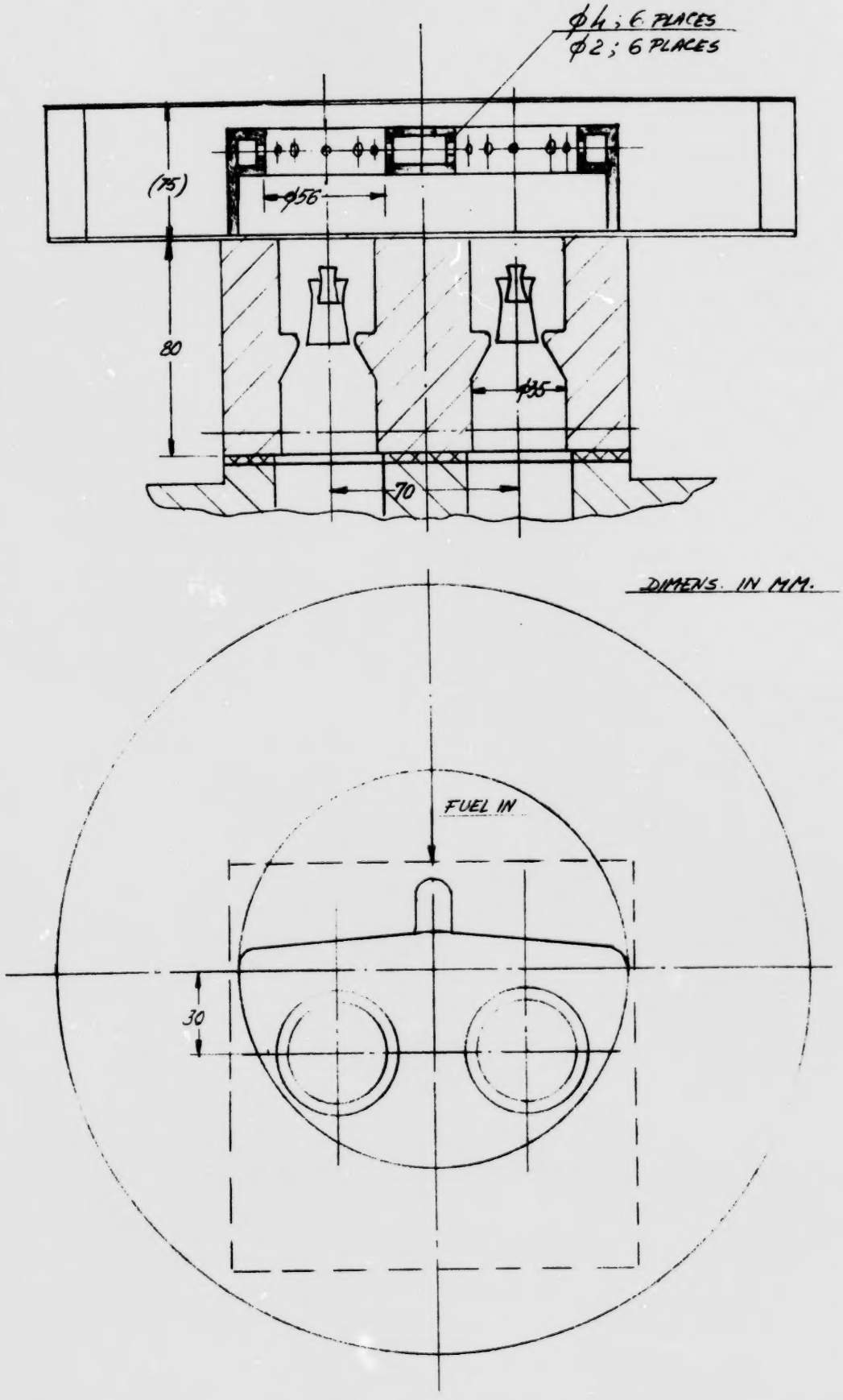


Figure 4-5: Schematic view of C.K. propane carburetion system mounted on top of gasoline carburetor

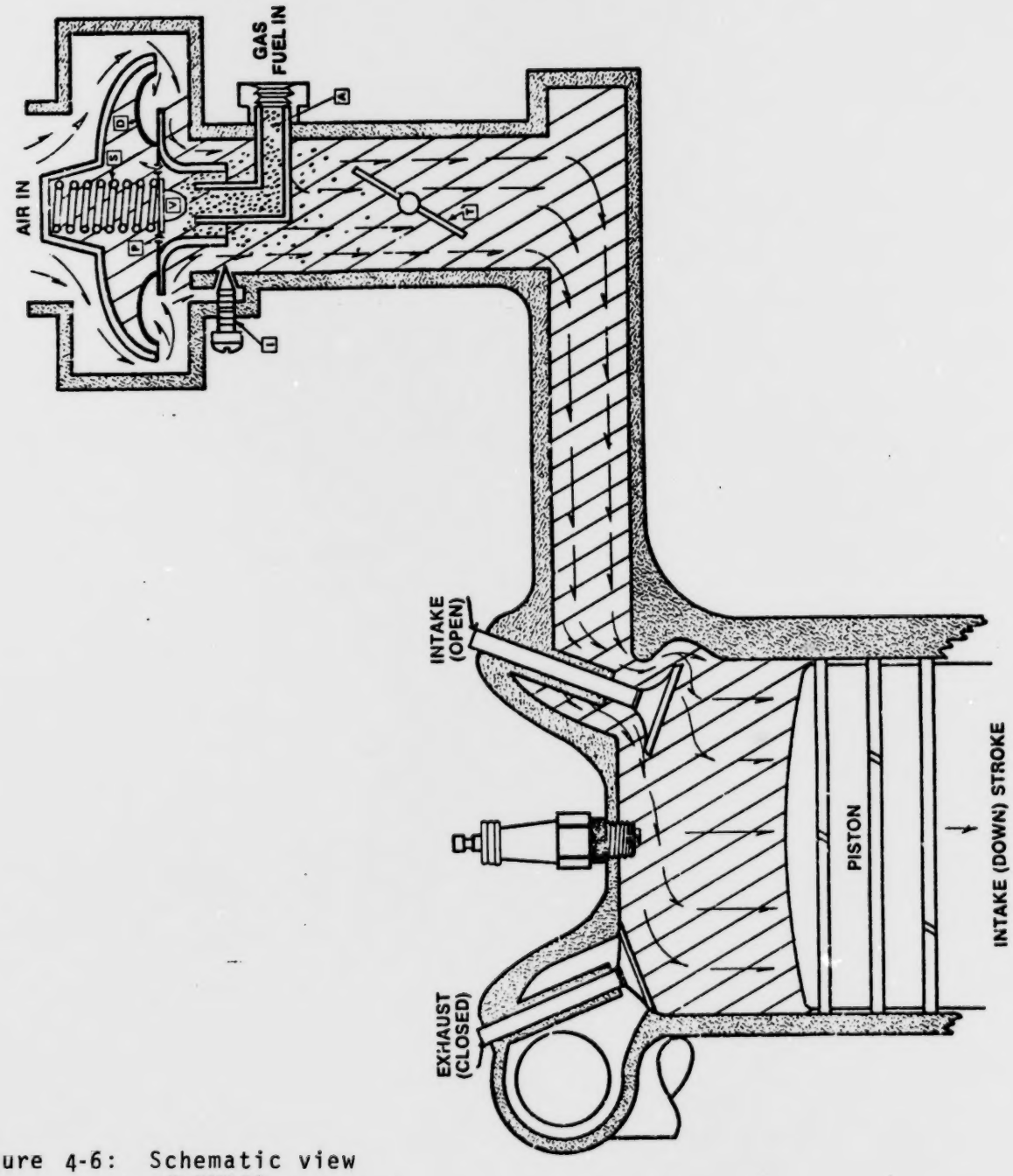


Figure 4-6: Schematic view of IMPCO propane carburetion system

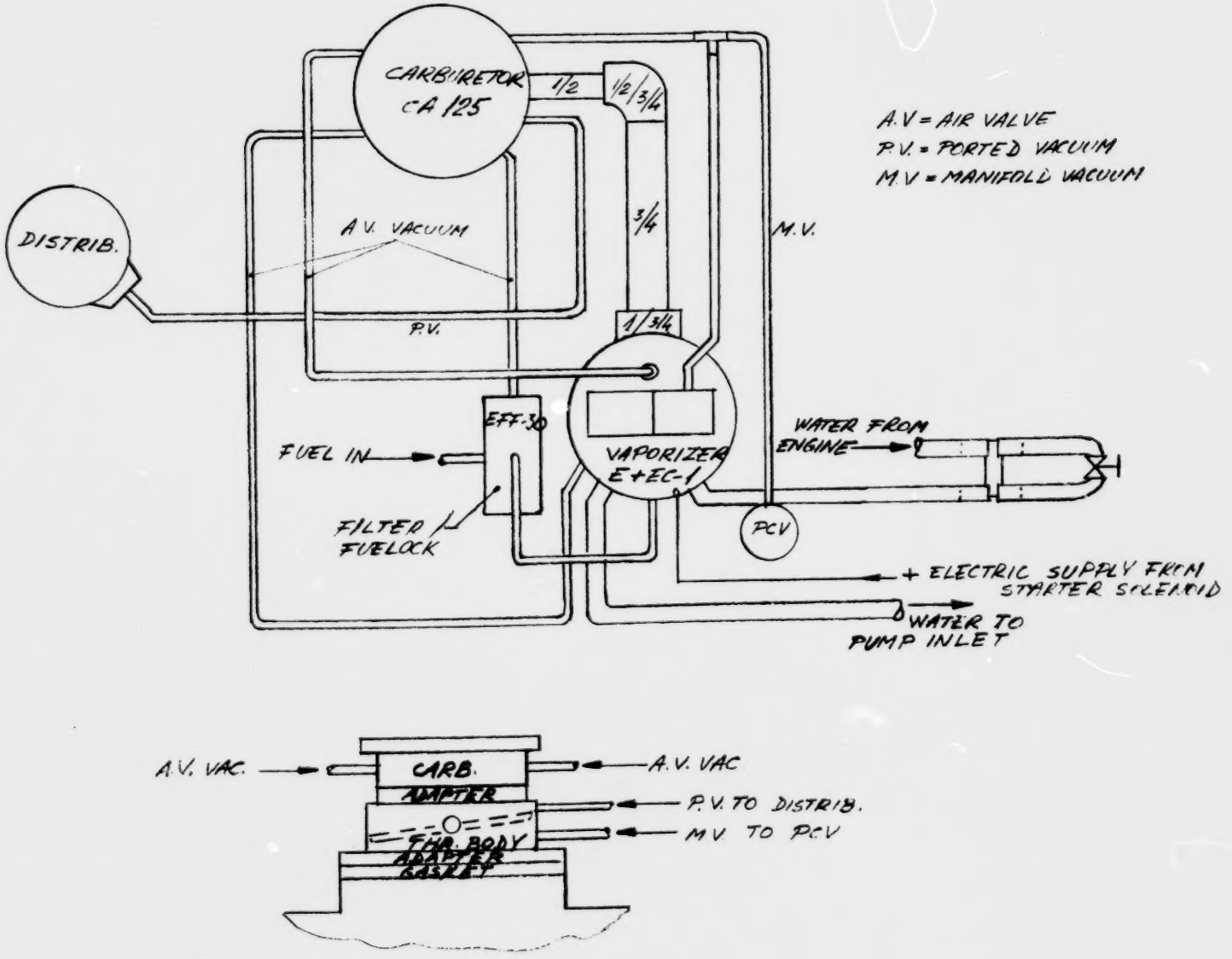


Fig. 4-7: "Impco" propane carburation system installed.

F.9

5. TEST PROCEDURE

The test procedure is based on SAE Standard J 816 b - "Engine Test Code - Spark Ignition and Diesel" and "GM Engine Test Code" - VI edition, test 1 - "Full throttle, as installed".

During the test the "net power" as defined by SAE Standard is measured -- the engine is equipped with all the built-in accessories (fuel, oil and coolant pumps) and all the accessories necessary to perform its intended functions unaided (intake, exhaust, cooling, electric and emissions control systems). Specifically,this includes:

- air cleaner
- radiator (not in use)
- fan
- all standard emissions controls (Fig. 3.1-1 and 3.2-2)
- catalytic converter
- muffler
- alternator
- starter
- battery

The parameters measured during the test are:

- engine rotational speed, N [rpm]
- torque, T [lb ft.]

- mass fuel consumption, W [lb]
- exhaust gas temperature [°F]
- spark advance BTDC [°]
- manifold vacuum [in Hg]
- outlet cooling water temperature [°F]
- lubrication oil pressure at filter [psi]
- relative throttle position
- barometric pressure, B [in Hg]
- ambient temperature, t [°F]
- wet and dry bulb temperatures [°F] for water vapour pressure in atmosphere, e [in Hg]
- HC (n-hexane equivalent) emission [ppm]
- CO emission [%]
- CO_2 emission [%]
- NO emission [ppm]

The following parameters are calculated for correction of data at standard ambient conditions:

- brake power, observed (at test conditions), b_{pt} [hp]
- brake mean effective pressure, observed, $bmep_t$ [lb/in^2]
- mechanical efficiency, n [%]
- friction power, observed, fp [hp]
- mass fuel consumption per hour, observed, F_t [lb/h]
- brake specific fuel consumption, observed, $bsfc_t$ [lb/hp·h]
- barometric pressure, corrected for dry air conditions, B_d [in Hg]
- correction factor for standard atmospheric conditions, C_s

- brake power, corrected, bp_c [hp]
- torque, corrected T_c [lb.ft]
- brake mean effective pressure, corrected, $bmep_c$ [lb/in^2]

The calculations are detailed in Appendix 1.

The air-fuel ratio (A/F) is calculated from the emission components (HC, CO, CO_2, O_2 and NO). The theoretical background of the method is presented in Appendix 2. The operations during the test are listed below:

a) stabilize thermal regime of the engine.
b) measure and record atmospheric conditions.
c) load the engine at WOT (wide open throttle) to obtain the minimum stabilized speed and record the listed parameters for a 3 minute period.(4 minutes in some tests).
d) decrease the load at the same speed at 2/3, 1/3 and minimum obtainable from maximum load and record the listed parameters for a 3 minute period, (4 minutes in some tests).
e) repeat steps c and d each 600 rpm, up to 4,200 rpm, to cover the peak obtainable power for the test engine.
f) repeat all the steps a to e to check for consistency of data.

The test with gasoline was conducted with the following settings:

- static timing 8° BTDC at 1200 rpm (instruction on the emissions sticker of the engine)
- $190 \pm 10^{\circ}F$ thermostatic control of cooling water outlet from engine (SAE for dynamometer testing)
- all emissions controls in place and operational

The tests with propane were conducted at the settings listed below, recommended by the majority of propane carburetion systems suppliess:

- 160°F thermostatic control of cooling water outlet from engine
- spark plugs one step colder (Champion model RBL 13Y6), with gap reduced to 0.040 in (-0.005 in.)
- static timing: 12°BTDC @ 600 rpm
- distributor with one centrifugal advance apring removed
- vacuum advance in normal operation
- EGR valve in place, isolated
- inlet manifold heating isolated

Fuels: gasoline-regular unleaded, propane-for automotive use, commercial grades.

6. TEST RESULTS

The test results are presented in their final form. Complete data acquisition and reduction forms are available upon request. All data values represent the average of at least two test runs.

The baseline gasoline test data in this report have been revised and replace those in the Phase II Report. The difference is determined by an improved method of measurement used in the revised test:

- the gasoline is supplied from two tanks - one for fuel metering during the test period, placed on the 'METLER' balance, and one for auxiliary supply, to keep the engine running between test periods. The change of supply is done by electrovalves controlled by an electronic timer. This arrangement changes the former dynamic measurement of fuel supply from one tank on the balance into a static measurement after the end of the test period, most suitable for the 'METLER' system, designed for high accuracy under static conditions.
- the balance stability detector was switched off, permitting unrestricted output of data. In the former setting with this switch on, the accuracy was supposed improved, but instead the presence of external distrubances abounding in the test cell (hot air drafts, vibration) disabled the output for relative long periods and especially blocked the zero setting at the start of the test period for 15-20 seconds. This shortened the time the fuel was really measured, offering low results for consumption.

- the test period was increased from 3 to 4 minutes, improving the accuracy of measurement.

The stability detector problem was observed and corrected after the first gasoline test, so all the propane systems tests are free of this error. The repeated IMPCO test had results very close to the first one, demonstrating the reliability of data for the propane systems.

Table 6-2 and Figure 6-1 give corrected brake power at wide open throttle (WOT). For ease of comparison, for each data point, the percentage difference between each propane carburetion system and the gasoline system is also presented. The power developed with propane is 3.7 to 15.5% higher at 1300 rpm, equals the power developed with gasoline at 2400 to 3000 rpm and is 3.7 to 15.5% lower at 4150 rpm. In the past a reduction of power with propane was considered normal and explained by the reduction in air-fuel charge density due to the increase of temperature in the inlet manifold as an effect of vaporizer heating. Results of the inlet manifold charge temperature measurements are presented in Table 6-3 and Figure 6-2.

With the cooling water at 160^{o} and the cross-heating of the inlet

Table 6-2: WOT Performance (Maximum power)

$\frac{\text{hp}}{\text{\% vs gasoline}}$, average values

CARBURETION SYSTEM	Engine speed (RPM)					
	1300*	1800	2400	3000	3600	4150*
GASOLINE ORIGINAL	40.48	57.67	74.06	88.39	100.43	112.75
BEAM	44.60 / +10.17	61.62 / +6.85	76.07 / +2.71	88.25 / -0.16	94.46 / -5.94	95.25 / -15.52
A.F.S.	41.99 / +3.73	59.66 / +3.45	75.65 / +2.15	86.59 / -2.04	93.20 / -7.20	96.10 / -14.77
ALGAS	43.09 / +6.45	59.75 / +3.61	75.09 / +1.39	84.71 / -4.16	94.12 / -6.28	96 / -14.86
CENTURY	46.74 / +15.46	58.39 / +1.25	75.25 / +1.61	86.94 / -1.64	98.11 / -2.31	102.44 / -9.14
C.F.S.	44.52 / +10.97	60.59 / +5.06	75.05 / +1.34	83.17 / -5.91	91.86 / -8.53	99.78 / -11.50
FUELCON	44.40 / +9.68	60.93 / +5.65	78.05 / +5.39	88.63 / +0.27	99.18 / -1.24	108.62 / -3.66
C.K.	44.07 / +8.87	60.64 / +5.15	75.76 / +2.30	85.12 / -3.70	98.70 / -1.72	103.00 / -8.65
IMPCO	42.90 / +5.98	57.41 / -0.45	75.16 / +1.49	88.57 / +0.20	98.62 / -1.80	99.98 / -11.33

* extrapolated values

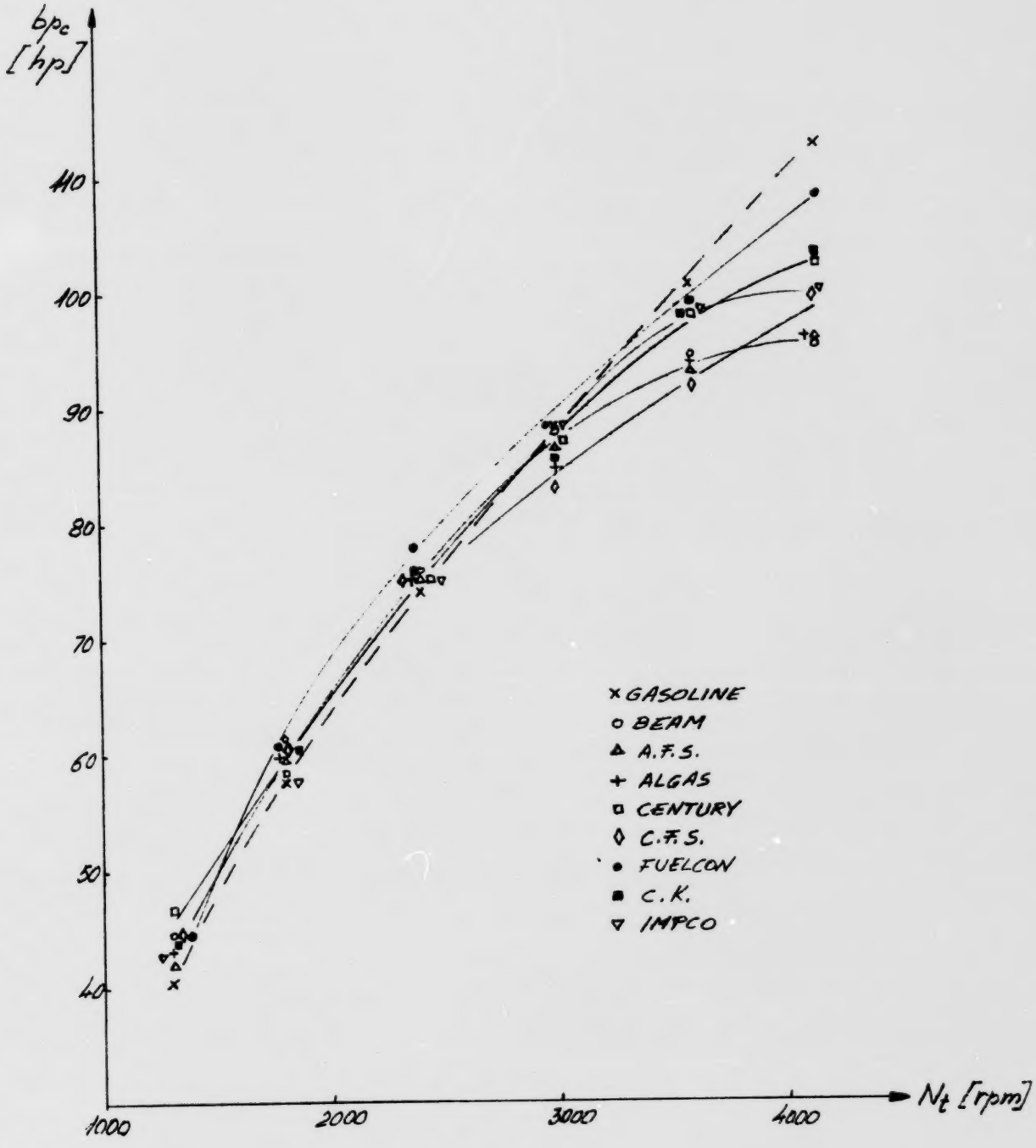


Figure 6-1: Comparison of power at wide open throttle

Table 6-3 : Inlet manifold air-fuel charge temperature
^{o}F

LOAD %	CARBURETION SYSTEM	Engine speed (RPM)						
		600	1300 *	1800	2400	3000	3600	4150
100	Gasoline III (1)		127	113	117	117	122	127
	Propane II (2)		176	177	176	176	178	187
	Propane III (3)		117	114	113	118	122	131
66	Gasoline III		140	129	129	127	131	135
	Propane II		174	171	176	178	186	189
	Propane III		116	113	113	120	120	124
33	Gasoline III		131	135	126	122	134	-
	Propane II		174	172	172	164	171	-
	Propane III		117	115	114	122	123	-
10	Gasoline III	138	122	131	135	131	132	-
	Propane II	176	158	172	172	163	172	-
	Propane III	128	118	117	116	122	125	-

Obs.: - roman numbers according to test order
- temp. after 4 minutes at indicated load and speed

(1) = with EGR and cross-heating active, standard configurations for gasoline, cooling water 190±10° F

(2) = with EGR and cross-heating active, cooling water 190±10° F

(3) = without EGR and cross-heating, standard configuration for propane, cooling water 160±10°F

* extrapolated values

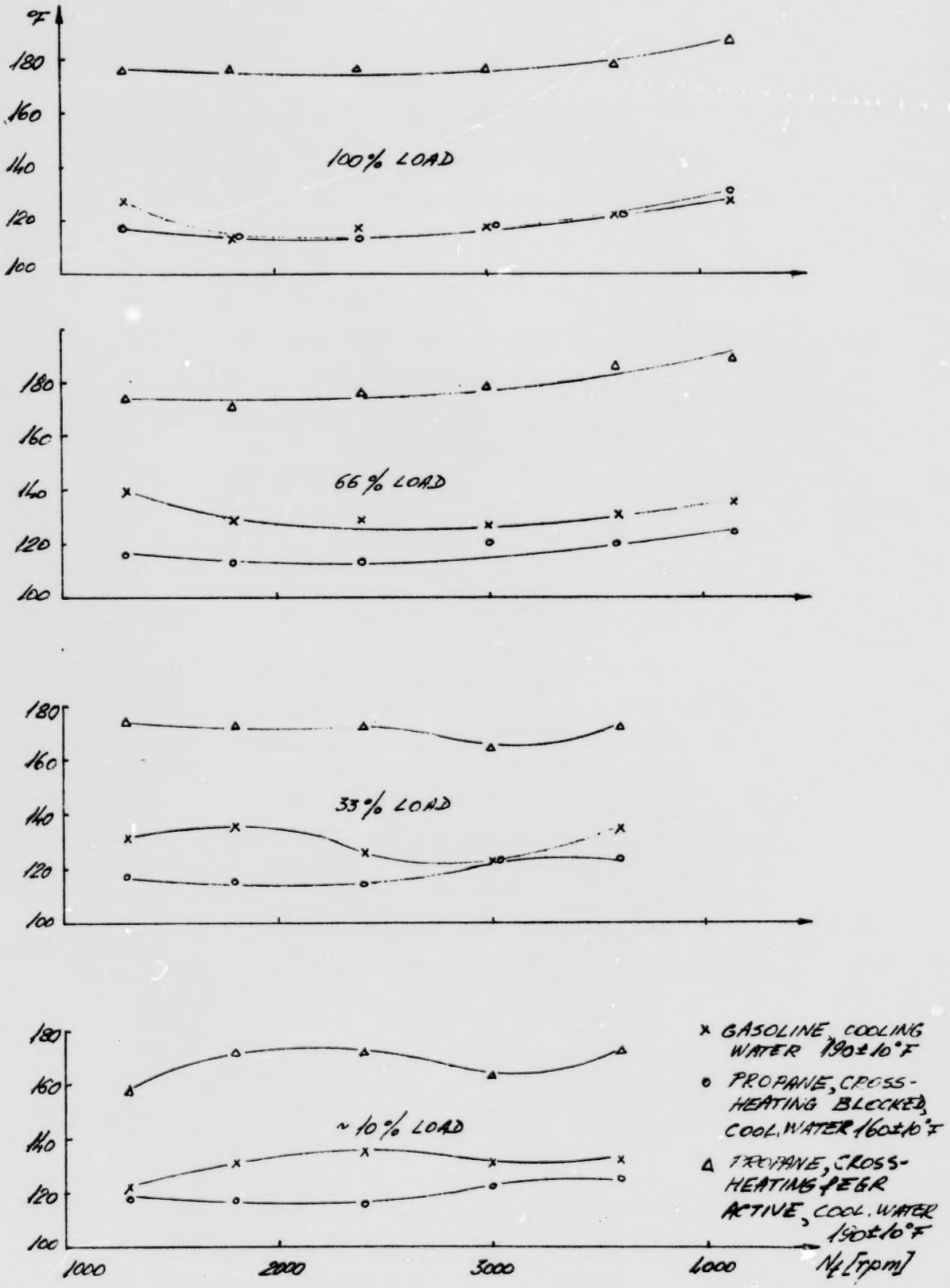


Figure 6.2 : Inlet manifold air-fuel charge temperature

manifold blocked, the temperature of the charge with propane is comparable with that of gasoline and even lower. The reason for the differences in power output is consequently not the inlet charge temperature and it was found to be the difference in air-fuel ratio. In Figure 6-3 is presented the correlation between A/F and the WOT power at different speeds. The propane carburetion systems running richer naturally develop more power, and the influence of A/F ratio is stronger at higher speeds (increase of 1.9% per each point of A/F at 1300 rpm, up to 7.9 % at 4150 rpm). The systems operating at A/F one point richer than stoichiometric - as is the case with gasoline - are developing power equal or higher than the baseline gasoline system up to 3000 rpm.

For the conclusions on this topic and for all the comparisons following on this Report, it is necessary to underline that loads over 40-50% of maximum at WOT and speeds over 60-70% of maximum are generally of no interest for real driving. They are used in the present work for a complete mapping of the engine, but the result in favour of one system or another at high loads and speeds has little or no effect in comparing the two fuels in fleets.

Back to the subject of inlet charge temperature, a test with the cooling water at 190°F and with the cross-over heating and EGR valve active - as for gasoline - shows an increase of inlet charge temperature of up to 66°F and an average decrease in power of 5% on one system (IMPCO).

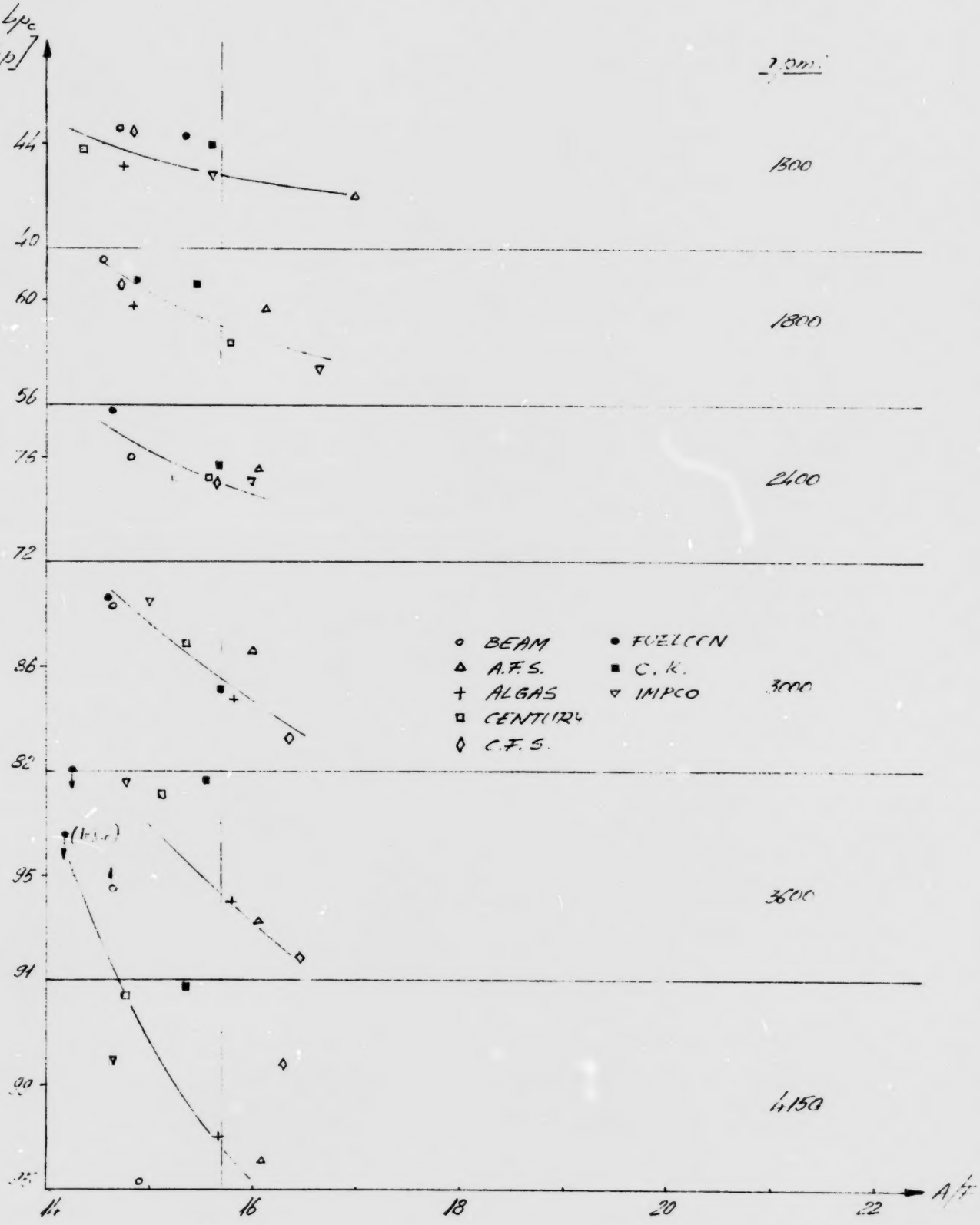


Figure 6-3: Correlation between WOT power and A/F ratio

Tables 6-4 to 6-6 contain the measured brake specific fuel consumption (BSFC) for 100% load (WOT) and for 66 and 33% of maximum load. Table 6-7 gives the total fuel consumption per hour for the minimum load obtainable with the GO-POWER hydraulic dynamometer (about 10% of WOT load). Figure 6-4 gives the same results in graphical form. On this weight base the LPG carburetion systems have a consistently lower specific fuel consumption at full load (up to 19.3%). At partial loads the LPG systems have better fuel consumption at lower speeds (up to 2500 - 3000 rpm) and the gasoline system at higher speeds.

Tables 6-8 to 6-11 present BSFC compared to that of gasoline on the basis of energy contained in the fuel. This allows a true comparison of efficiency of the gasoline and propane systems. The values of energy efficiency of propane systems vs. the gasoline are plotted in Figure 6-5. From the beginning the spread of results has to be noted. The average values for each load and speed are presented in Table 6-12, as well as the overall average values for each load. The energy efficiency of the propane systems varies on average between 14.7% higher and 17.7% lower compared with the baseline gasoline system. For all speeds, at full load the average energy efficiency is 4.5% higher, at 66% load - 7.5% lower, at 33% load - 6.1% lower and at 10% load - 1.3% higher (up to 2400 rpm - 8% higher). But those results do not reflect a difference of principle between the two carburetions analyzed. There are big differences between different constructions of propane carburetion systems and the less successful constructions strongly influence the

Table: 6-4: Brake Specific Fuel Consumption
Mass Base

lb/hp.h / % vs Gasoline , average values

100% LOAD

CARBURETION SYSTEM	Engine speed (RPM)					
	1300*	1800	2400	3000	3600	4150*
GASOLINE ORIGINAL	.468	.482	.475	.494	.522	.512
BEAM	.428 -8.55	.422 -12.45	.443 -6.74	.473 -4.25	.499 -4.41	.520 +1.56
A.F.S.	.390 -16.67	.389 -19.29	.392 -17.47	.432 -12.55	.467 -10.54	.492 -3.91
ALGAS	.419 -10.47	.409 -15.15	.420 -11.58	.442 -10.53	.455 -12.84	.508 -0.01
CENTURY	.446 -4.7	.395 -18.5	.413 -13.52	.439 -11.13	.467 -10.54	.511 -0.195
C.F.S.	.429 -8,33	.417 -13.49	.418 -12.0	.443 -10.32	.463 -11.30	.465 -9.18
FUELCON	.411 -12.18	.389 -19.29	.427 -10.11	.465 -5.87	.491 -5.94	.501 -2.15
C.K.	.436 -6.84	.420 -12.86	.432 -9.05	.460 -6.88	.474 -9.20	.497 -2.93
IMPCO	.420 -10.26	.392 -18.67	.414 -12.84	.462 -6.48	.483 -7.47	.540 +5.47

* extrapolated values

Table 6-5 : Brake Specific Fuel Consumption
Mass Base

lb/hp.h , average values
% vs Gasoline

66% LOAD

CARBURETION SYSTEM	Engine speed (RPM)					
	1300*	1800	2400	3000	3600	4150*
GASOLINE ORIGINAL	.479	.458	.461	.476	.511	.489
BEAM	.434 -9.39	.429 -6.33	.455 -1.30	.488 +2.52	.523 +2.34	.579 +18.40
A.F.S.	.442 -7.72	.442 -3.49	.462 +.22	.490 +2.94	.540 +5.68	.600 +22.70
ALGAS	.438 -8.56	.438 -4.37	.458 -0.65	.491 +3.15	.527 +3.13	.577 +18.00
CENTURY	.418 -12.73	.419 -8.52	.447 -3.04	.481 +1.05	.506 -0.95	.526 +7.57
C.F.S.	.445 -7.10	.485 +5.89	.508 +10.20	.529 +11.13	.545 +6.65	.537 +9.82
FUELCON	.470 -1.88	.458 0.00	.473 +2.60	.547 +14.92	.555 +8.61	.554 +13.29
C.K.	.452 -5.64	.451 -1.53	.473 +2.60	.522 +9.66	.514 +0.59	.527 +7.77
IMPCO	.420 -12.32	.421 -8.08	.466 +1.08	.464 -2.52	.503 -1.57	.539 +10.22

* extrapolated values

Table 6-6: Brake Specific Fuel Consumption
Mass Base

$\frac{\text{lb/hp. h}}{\text{\% vs Gasoline}}$, average values

33% LOAD

CARBURETION SYSTEM	Engine speed (RPM)					
	1300*	1800	2400	3000	3600	4150*
GASOLINE ORIGINAL	.566	.625	.633	.643	.646	
BEAM	.536 -5.30	.564 -9.76	.588 -7.11	.643 0.00	.712 +10.22	
A.F.S.	.572 +1.06	.557 -10.88	.609 -3.79	.663 +3.11	.759 +17.49	
ALGAS	.570 +0.71	.557 -10.88	.600 -5.21	.644 +0.16	.739 +14.40	
CENTURY	.512 -9.54	.522 -16.48	.581 -8.21	.629 -2.18	.681 +5.42	
C.F.S.	.529 -6.54	.570 -8.80	.671 +6.00	.785 +22.08	.794 22.91	
FUELCON	.645 +13.96	.642 +2.72	.635 +0.32	.708 +10.11	.686 +6.19	
C.K.	.599 +5.83	.579 +6.19	.625 -1.26	.690 +7.31	.702 +8.67	
IMPCO	.531 -6.18	.550 -12.00	.576 -9.00	.609 -5.29	.698 +8.05	

* extrapolated values

Table 6-7: Brake Fuel Consumption
Mass Base

lb/h
% vs Gasoline, average values

~10% LOAD

CARBURETION SYSTEM	Engine speed (RPM)					
	1300*	1800	2400	3000	3600	4150*
GASOLINE ORIGINAL	5.59	8.68	11.35	14.41	19.24	
BEAM	4.43 -20.75	6.76 -22.12	10.00 -11.89	14.41 0.00	19.83 +3.07	
A.F.S.	4.50 -19.50	6.90 -20.51	10.65 -6.17	14.66 +1.73	20.33 +5.67	
ALGAS	4.53 -18.96	6.86 -20.97	10.14 -10.66	14.55 +.97	19.98 +3.85	
CENTURY	4.96 -11.29	6.79 -21.77	10.23 -9.87	14.25 +1.11	18.43 -4.21	
C.F.S.	4.60 -17.71	6.95 -19.93	10.25 -9.69	15.96 +10.76	20.95 +8.89	
FUELCON	6.37 +13.95	7.94 -8.52	12.10 +6.61	17.00 +17.97	19.10 -0.73	
C.K.	4.81 -13.95	6.97 -19.70	10.96 -3.44	15.46 +7.29	19.09 -0.80	
IMPCO	5.13 -8.23	7.04 -18.89	10.09 -11.10	14.34 -0.49	18.93 -1.61	

* extrapolated values

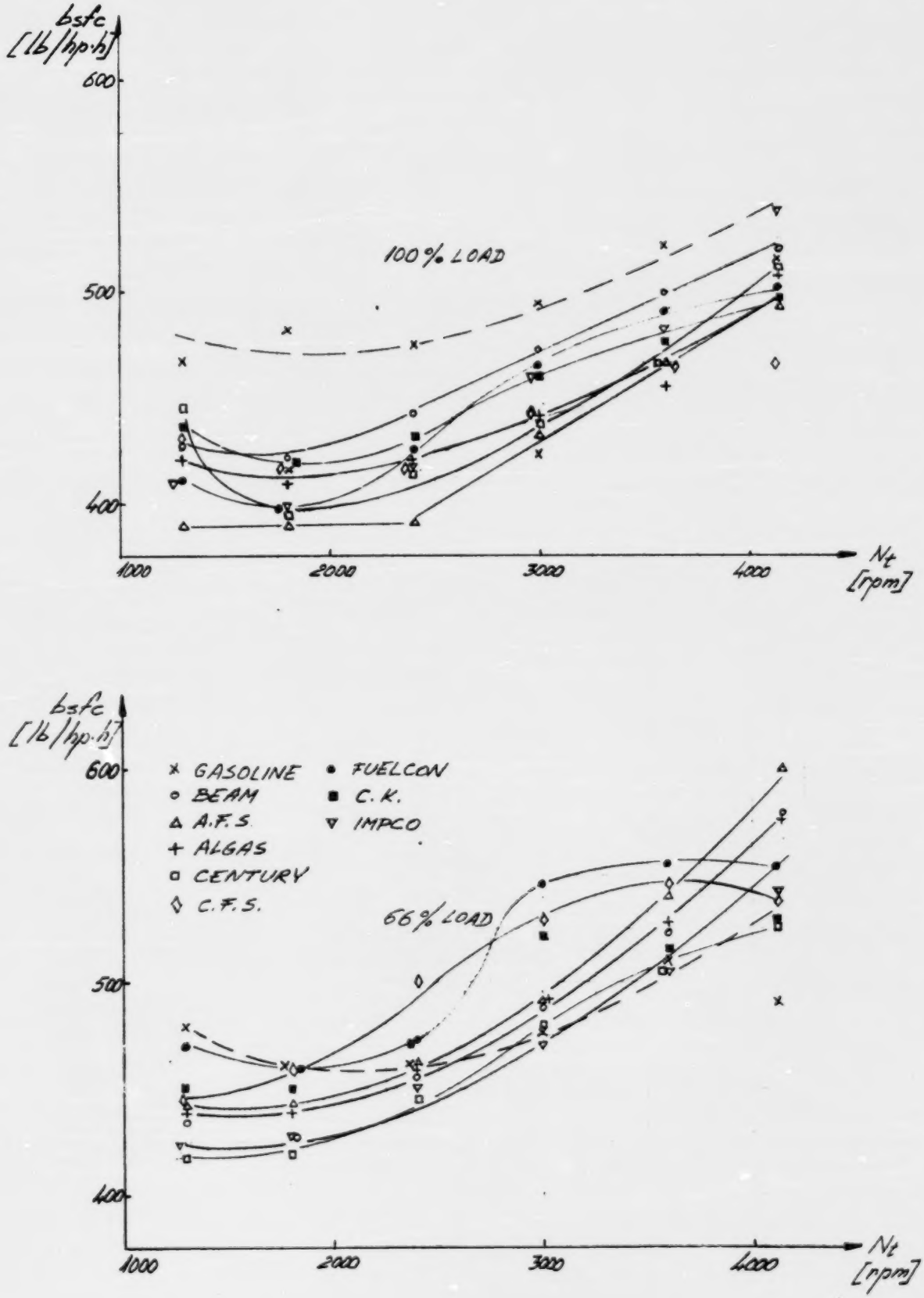
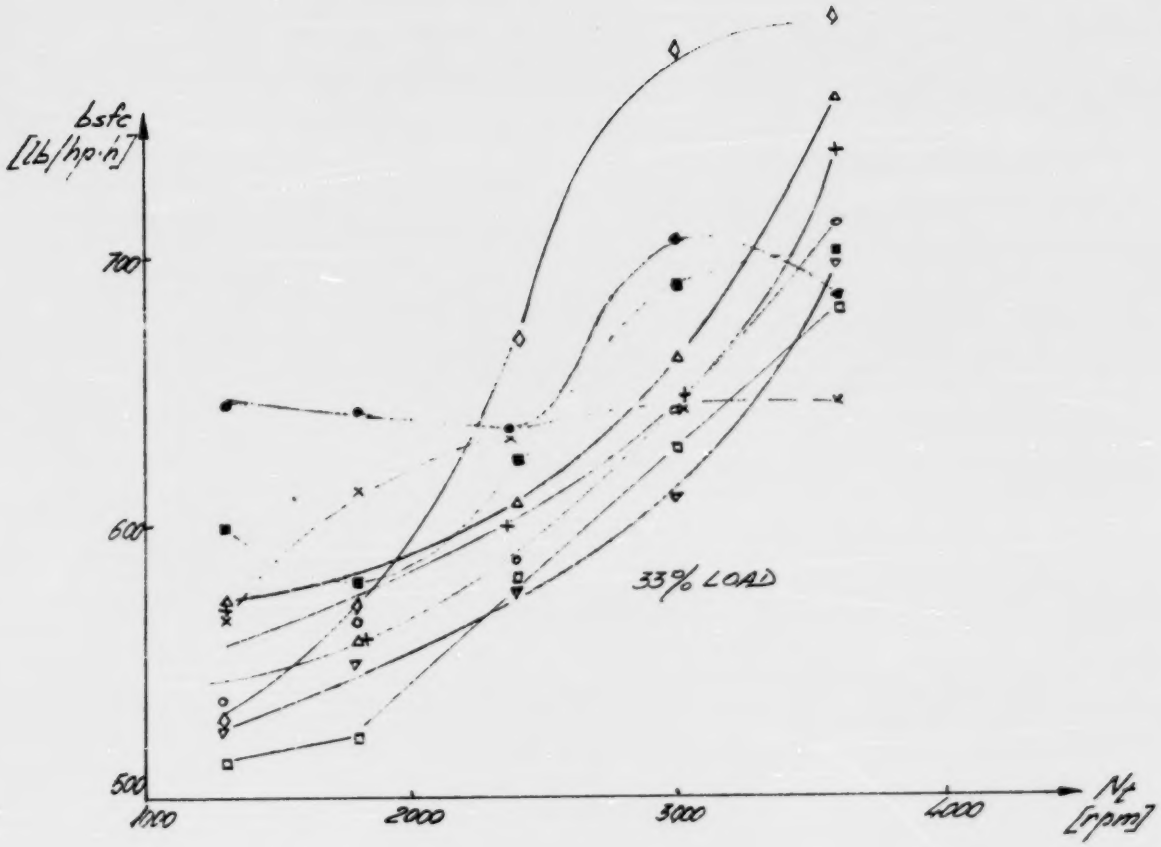


Figure 6-4.1: Comparison of brake specific fuel consumption - mass base



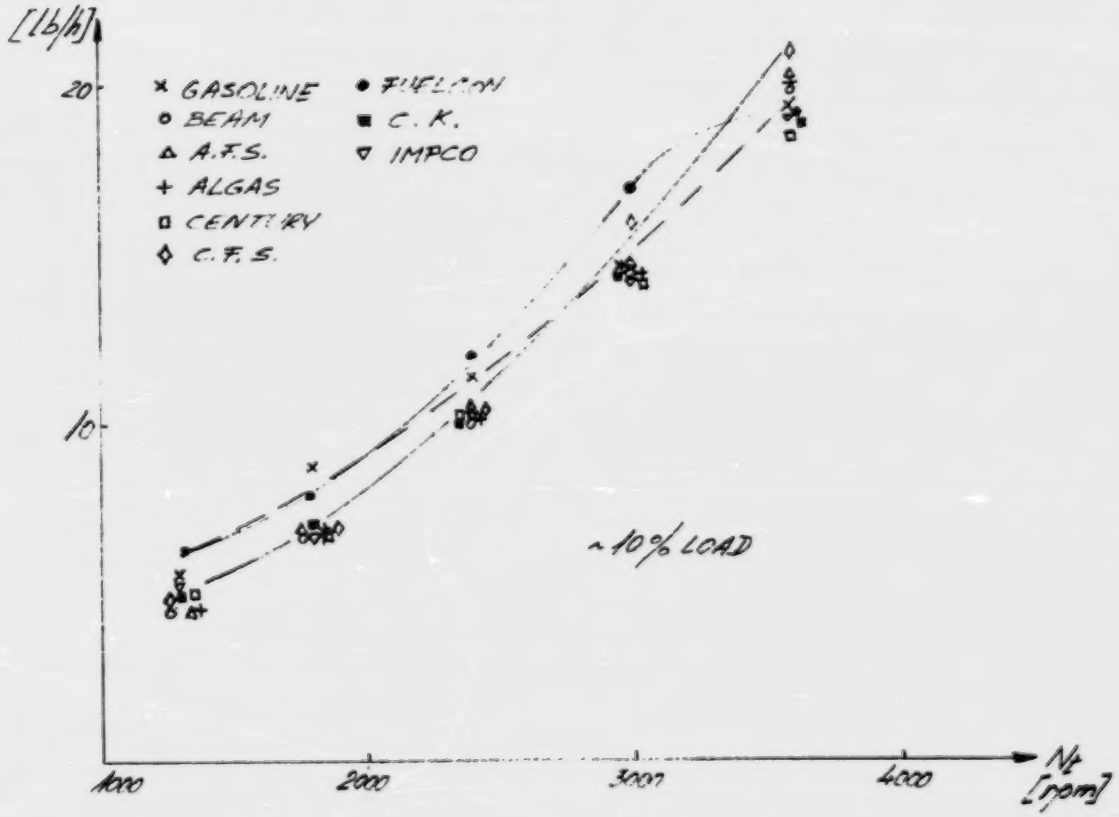


Figure 6-4.2: Comparison of brake specific fuel consumption - mass base (contin.)

Table 6-8: Brake Specific Fuel Consumption
Energy Base

kcal/hp.h , average values
% vs Gasoline

100% LOAD

CARBURETION SYSTEM	Engine speed (RPM)					
	1300*	1800	2400	3000	3600	4150*
GASOLINE ORIGINAL	2231	2278	2264	2355	2488	2450
BEAM	2151 -3.58	2121 -7.69	2226 -1.69	2377 +.94	2507 +.75	2613 +6.64
A.F.S.	1960 -12.15	1955 -14.91	1970 -13.00	2171 -7.80	2347 -5.68	2472 +.89
ALGAS	2105 -5.65	2055 -10.56	2111 -6.77	2221 -5.69	2286 -8.13	2553 +4.19
CENTURY	2241 +.45	1985 -13.61	2075 -8.36	2206 -6.32	2347 -5.68	2568 +4.81
C.F.S.	2156 -3.36	2095 -8.82	2100 -7.26	2226 -5.47	2327 -6.48	2337 -4.62
FUELCON	2065 -7.44	1955 -14.18	2146 -5.21	2337 -0.76	2467 -0.84	2518 +2.78
C.K.	2190 -1.84	2111 -7.33	2171 -4.11	2312 -1.83	2382 -4.26	2497 +1.92
IMPCO	2110 -5.42	1970 -13.52	2080 -8.13	2322 -1.40	2427 -2.45	2714 +10.78

* Extrapolated values

Net Heat of Combustion @ 25°C, constant p

- propane 11,078 kcal/kg (5,025 kcal/lb)
- gasoline 10,510 kcal/kg (4,767 kcal/lb)

Table 6-9: Brake Specific Fuel Consumption
Energy Base

kcal/hp.h / % vs Gasoline , average values

66% LOAD

CARBURETION SYSTEM	Engine speed (RPM)					
	1300*	1800	2400	3000	3600	4150*
GASOLINE ORIGINAL	2283	2183	2198	2269	2436	2331
BEAM	2181 / -4.48	2156 / -1.25	2291 / +4.25	2452 / +8.06	2628 / +7.88	2909 / +24.79
A.F.S.	2221 / -2.73	2221 / +1.73	2322 / +5.66	2462 / +8.50	2714 / +11.41	3015 / +29.34
ALGAS	2201 / -3.59	2201 / +.81	2301 / +4.71	2467 / +8.72	2648 / +8.71	2899 / +24.36
CENTURY	2100 / -3.6	2105 / -3.59	2246 / +2.20	2417 / +6.51	2543 / +0.70	2643 / +13.38
C.F.S.	2236 / -2.08	2437 / +11.62	2553 / +15.26	2658 / +17.14	2739 / +12.44	2698 / +15.75
FUELCON	2362 / +3.46	2301 / +5.41	2377 / +8.14	2749 / +21.15	2789 / +14.49	2784 / +19.43
C.K.	2271 / -0.53	2266 / +3.80	2377 / +8.14	2623 / +15.60	2583 / +6.03	2648 / +13.60
IMPCO	2110 / -7.58	2116 / -3.07	2342 / +6.55	2332 / +2.78	2528 / +3.78	2708 / +16.17

* extrapolated values

Table 6-10 Brake Specific Fuel Consumption
Energy Base

kcal/hp.h / % vs Gasoline , average values

33% LOAD

CARBURETION SYSTEM	Engine speed (RPM)					
	1300*	1800	2400	3000	3600	4150*
GASOLINE ORIGINAL	2698	2979	3018	3065	3079	
BEAM	2693 / -0.19	2834 / -4.87	2954 / -2.12	3231 / +5.42	3578 / +16.21	
A.F.S.	2874 / +6.52	2799 / -6.04	3060 / +1.39	3332 / +8.71	3814 / +23.87	
ALGAS	2864 / +6.15	2799 / -6.04	3015 / -0.10	3236 / +5.58	3713 / +20.59	
CENTURY	2572 / -4.67	2623 / -11.95	2920 / +3.25	3161 / +3.13	3422 / +11.14	
C.F.S.	2658 / -1.48	2864 / -3.86	3372 / +11.73	3945 / +28.71	3990 / +29.59	
FUELCON	3241 / +20.13	3226 / +8.29	3191 / +5.73	3558 / +16.08	3447 / +11.95	
C.K.	3010 / +11.56	2909 / -2.35	3141 / +4.08	3467 / +13.12	3528 / +14.58	
IMPCO	2668 / -1.11	2764 / -7.22	2894 / -4.11	3060 / -0.16	3507 / +13.90	

* extrapolated values

Table 6-11 : Brake Fuel Consumption
Energy Base

kcal/hp.h / % vs Gasoline , average values

~10% LOAD

CARBURETION SYSTEM	Engine speed (RPM)					
	1300*	1800	2400	3000	3600	4150*
GASOLINE ORIGINAL	26,648	41,378	54,105	68,692	91,717	
BEAM	22,261 / -16.46	33,969 / -17.90	50,250 / -7.13	72,410 / +5.41	99,646 / +8.64	
A.F.S.	22,613 / -15.14	34,673 / -16.20	53,516 / -1.09	73,667 / +7.24	102,158 / +11.38	
ALGAS	22,763 / -14.58	34,472 / -16.69	50,954 / -6.49	73,114 / +6.44	100,400 / +9.47	
CENTURY	24,924 / -6.47	34,120 / -17.54	51,406 / -4.99	71,606 / +4.24	92,611 / +0.97	
C.F.S.	23,115 / -13.26	34,924 / -15.60	51,506 / -4.80	80,199 / +16.75	105,274 / +14.78	
FUELCON	32,009 / +20.12	39,899 / -3.57	60,803 / +12.38	85,425 / +24.36	95,978 / +4.65	
C.K.	24,170 / -9.29	35,024 / -15.36	55,074 / +1.79	77,687 / +13.09	95,927 / +4.59	
IMPCO	25,778 / -3.26	35,376 / -14.51	50,702 / -6.29	72,059 / +4.90	95,123 / +3.71	

* extrapolated values

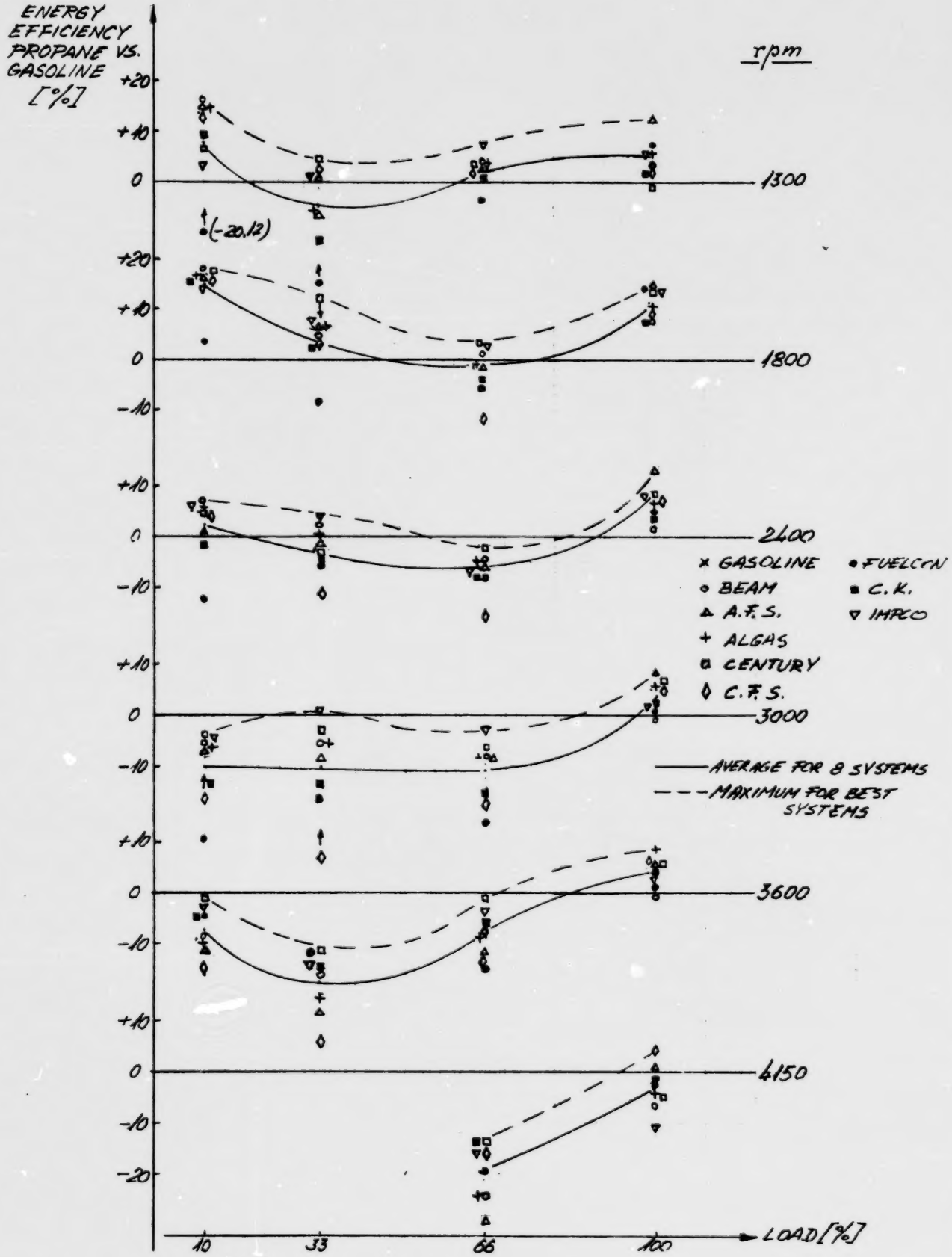


Figure 6-5: Energy efficiency of propane carburetion systems vs gasoline

Table 6-12 : Changes in energy efficiency % for the propane carburetion systems vs. gasoline

LOAD %	CARBURETION SYSTEM	Engine speed RPM 1300	1800	2400	3000	3600	4150	avg. for all speeds
Average for 8 systems								
100	-	+4.87	+11.33	+6.82	+3.54	+4.10	-3.42	+4.54
66	-	+2.64	-1.94	-6.86	-11.06	-8.18	-19.60	-7.50
33	-	-4.61	+4.26	-2.48	-10.07	-17.73	-	-6.13
10	-	+7.29	+14.67	+2.08	-10.30	-7.27	-	+1.29*
Maximum for the best systems								
100	A.F.S. ALGAS	+12.15	+14.91	+13.00	+7.80	+8.13	-0.89	+9.18
66	CENTURY IMPCO	+7.58	+3.59	-2.20	-2.78	-0.70	-13.38	-1.32
33	CENTURY IMPCO	+4.67	+11.95	+4.11	+0.16	-11.14	-	+1.95
10	BEAM CENTURY	+16.47	+17.90	+7.13	-4.24	-0.97	-	+7.25*

* +8.01 average
+13.83 maximum
for 1300 to 2400 rpm

average. Considering only the most successful constructions tested till now, the picture changes in favour of propane The best systems have an overall 2.0 to 9.2% better efficiency (except 66% load with only 1.3% reduction in efficiency), with up to 17.9% improvement at lower speeds, the most encountered in real driving.

Once again, the cause of the spread is the air-fuel ratio at which different propane systems run - see Figures 6-6 to 6-9. The systems running leaner show an improved fuel economy - about 5% for each point of A/F ratio at WOT and 2.7 to 4.1% at partial loads. As it is well known, the problem is very important at partial loads, where leaner mixtures are permitted and desirable for fuel economy improvement, as well as for emissions improvements, to be discussed later. The gasoline carburetor is very carefully designed to ensure partial loads mixture about 15% leaner than stoichiometric, over all the range of loads and speeds. Only a few propane carburetion systems tested ensure such an air-fuel ratio (approx. 18 forpropane),and only at some particular loads and speeds, where they really show good economy. Some run too lean and backfire was encountered.

Because propane and gasoline are sold in volumetric units, for an economic comparison the results are also presented on a volume base in Tables 6-13 to 6-16. Considering the density of propane, approximately 31% lighter than gasoline, even if the energy efficiency is in favour of propane, the consumption in volumetric units is still higher than gasoline.

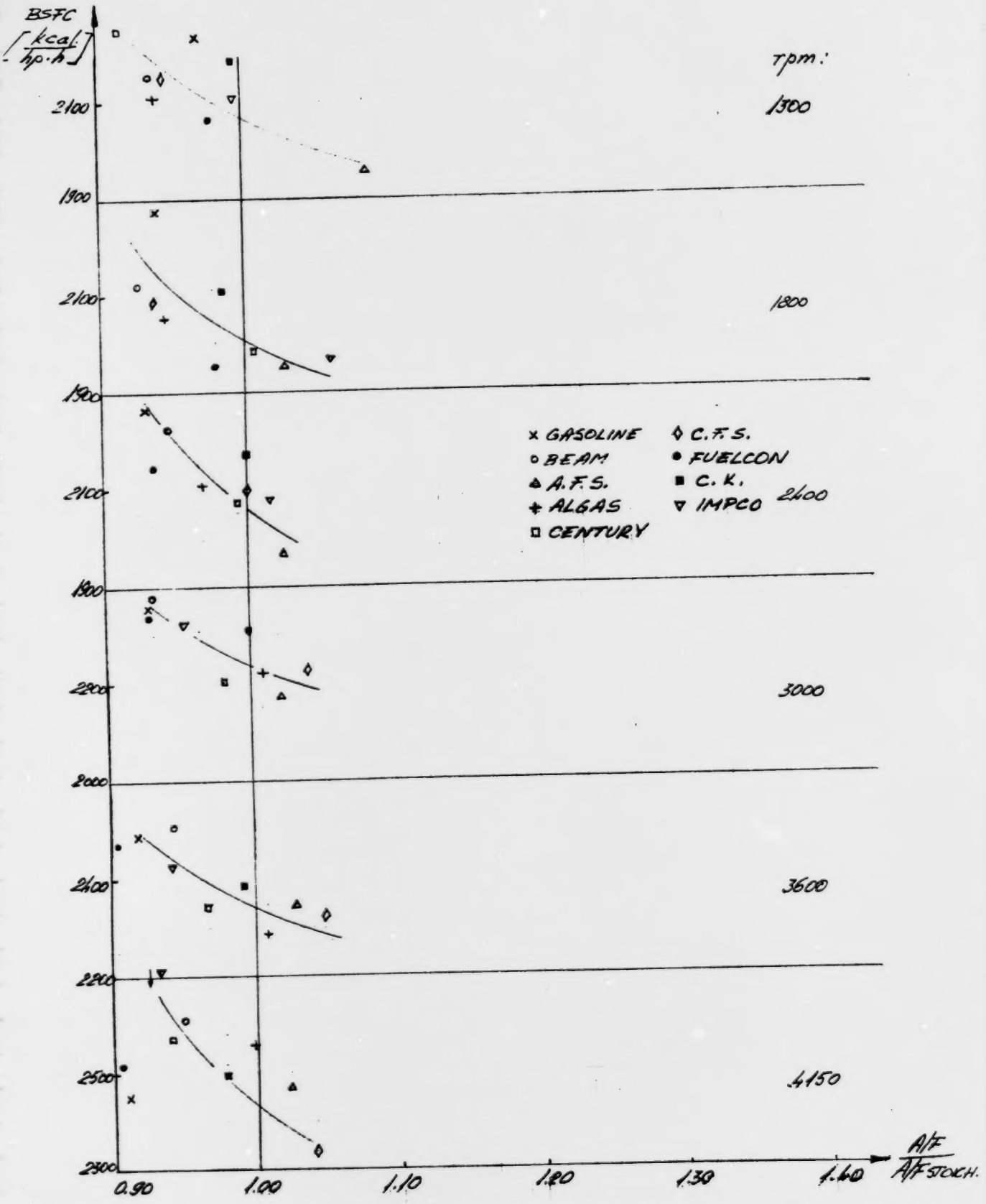


Figure 6-6 Correlation between Brake Specific Fuel Consumption and A/F ratio-100% load.

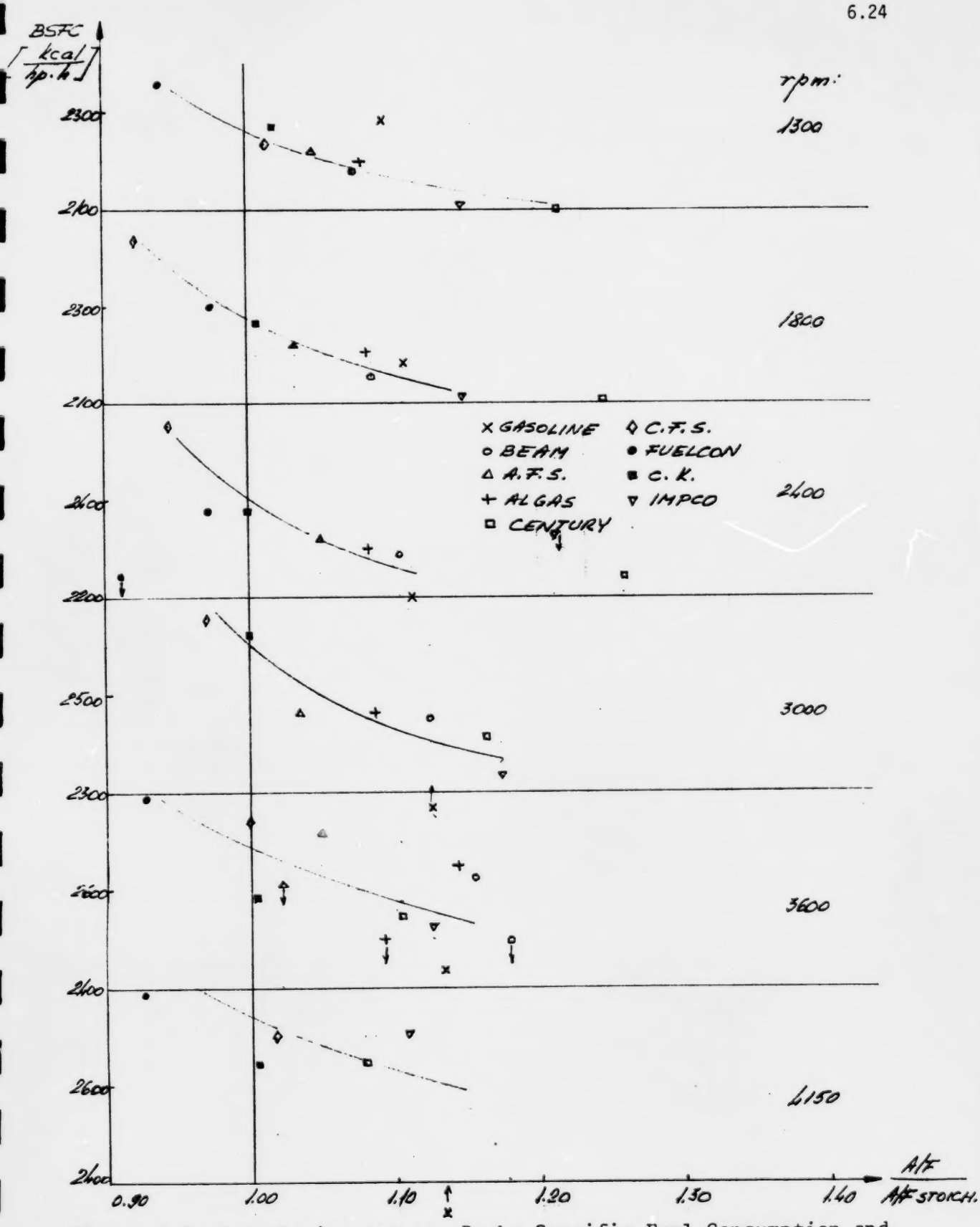


Figure 6-7: Correlation between Brake Specific Fuel Consumption and A/F ratio-66% load.

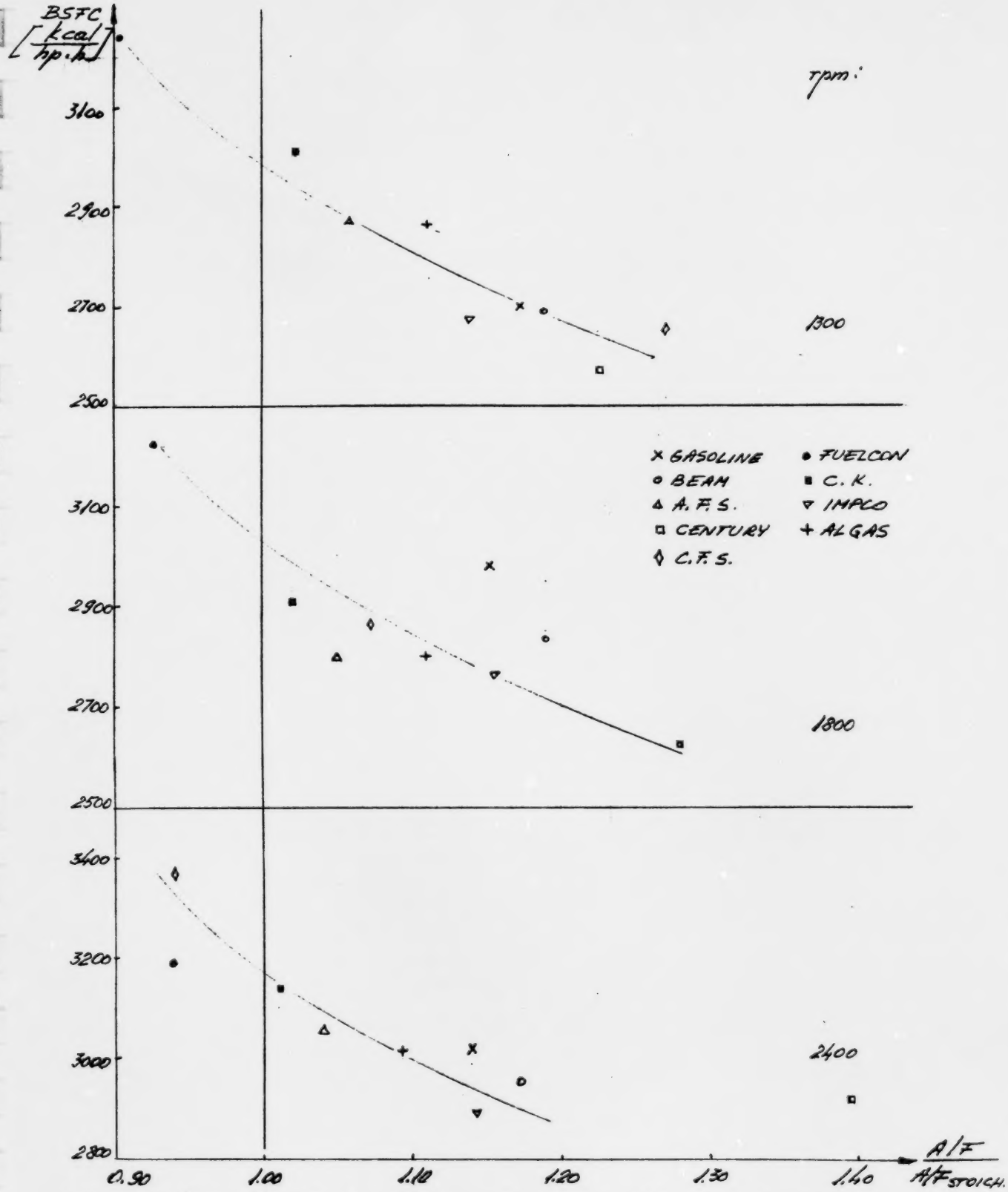


Figure 6.8.1: Correlation between Brake Specific Fuel Consumption and A/F ratio-33% load.

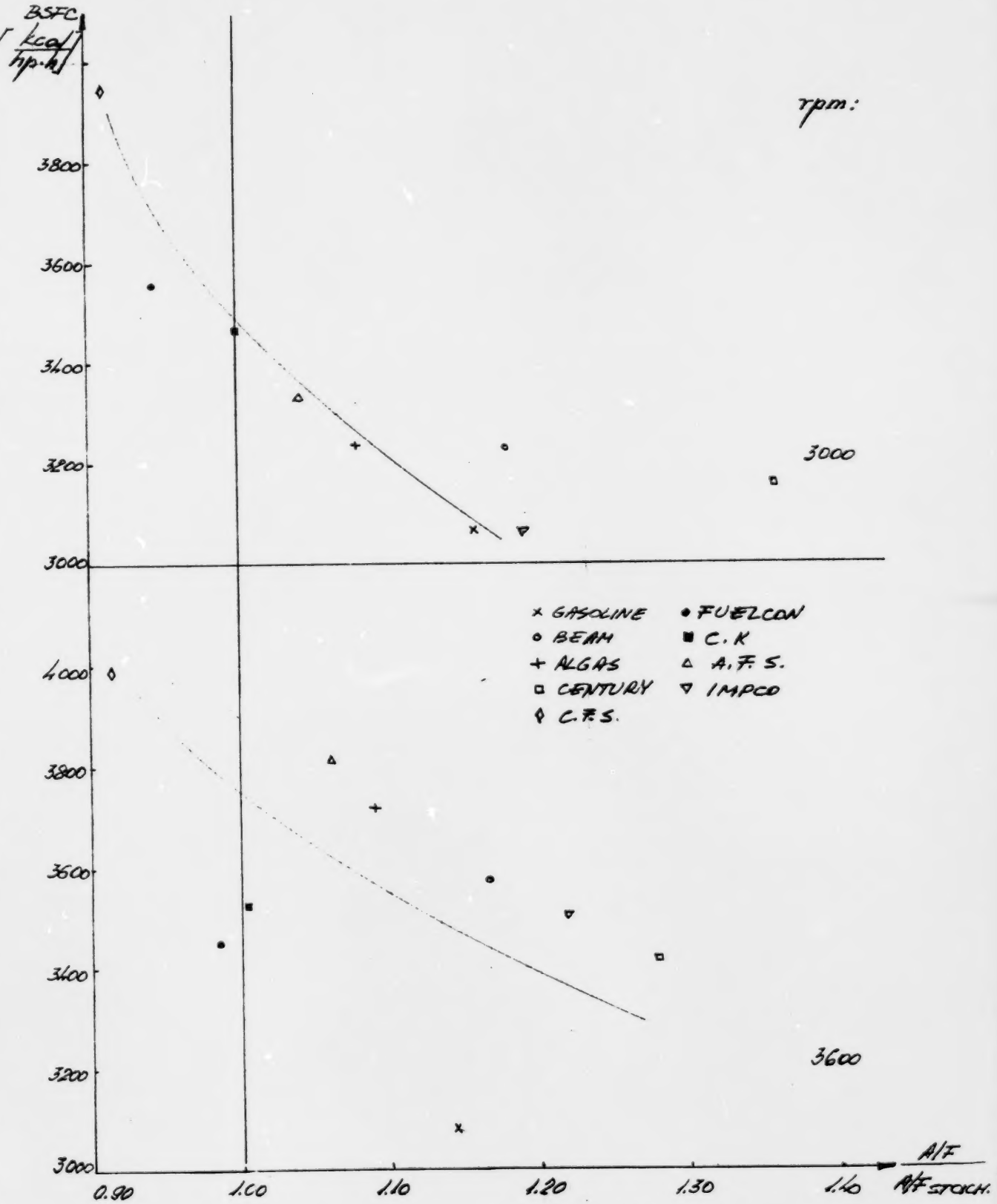


Figure 6-8.2: Correlation between Brake Specific Fuel Consumption and A/F ratio-33% load (cont'd.)

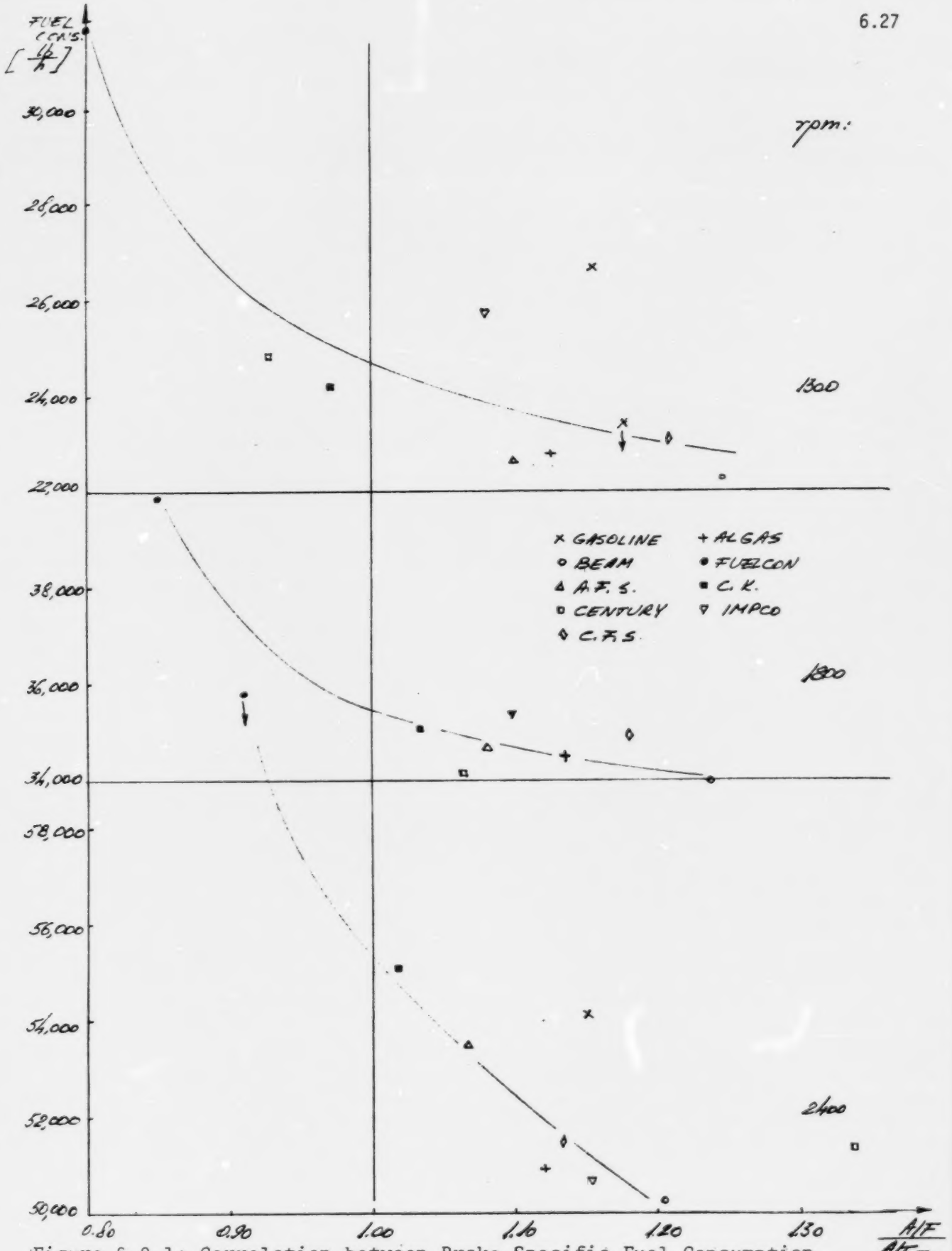


Figure 6-9.1: Correlation between Brake Specific Fuel Consumption and A/F ratio - 10% load.

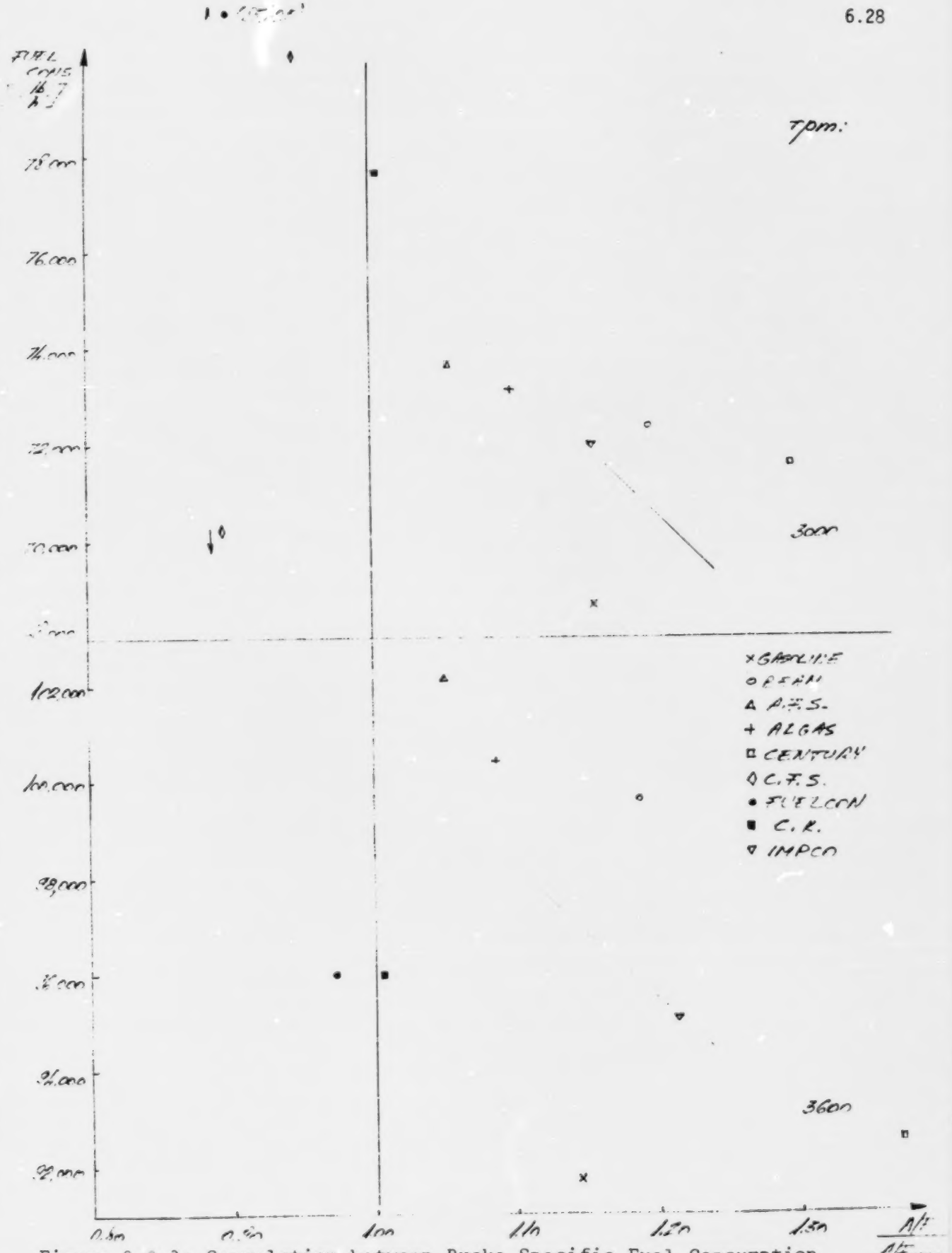


Figure 6-9.2: Correlation between Brake Specific Fuel Consumption and A/F ratio-10% load.

Table 6-13: Brake Specific Fuel Consumption
Volume Base

l/hp.h / % vs Gasoline , average values

100% LOAD

CARBURETION SYSTEM	Engine speed (RPM)					
	1300*	1800	2400	3000	3600	4150*
GASOLINE ORIGINAL	.288	.297	.292	.304	.321	.315
BEAM	.383 / +32.98	.378 / +27.14	.396 / +35.75	.423 / +39.22	.447 / +39.10	.465 / +47.62
A.F.S.	.349 / +21.17	.348 / +17.20	.351 / +20.12	.387 / +27.16	.418 / +30.18	.440 / +39.76
ALGAS	.375 / +30.18	.366 / +23.23	.376 / +28.70	.396 / +30.10	.407 / +26.83	.455 / +44.44
CENTURY	.399 / +38.57	.353 / +19.01	.370 / +26.50	.393 / +29.22	.418 / +30.18	.457 / +45.16
C.F.S.	.384 / +33.29	.373 / +25.63	.374 / +28.09	.396 / +30.39	.414 / +29.06	.416 / +32.09
FUELCON	.368 / +27.78	.348 / +17.17	.382 / +30.82	.416 / +36.84	.439 / +36.76	.448 / +42.22
C.K.	.390 / +35.42	.376 / +26.60	.387 / +32.53	.412 / +35.53	.424 / +32.09	.445 / +41.27
IMPCO	.376 / +30.56	.351 / +18.18	.370 / +26.71	.413 / +35.86	.432 / +34.58	.483 / +53.33

* extrapolated values

Density of liquid @ 60° F kg/l :

- propane 0.5069 (0.8948 l/lb)
- gasoline 0.737 @ 61° F API (0.6155 l/lb)

Table 6-14: Brake Specific Fuel Consumption
Volume Base

$\frac{\text{l/hp.h}}{\text{\% vs Gasoline}}$, average values

66% LOAD

CARBURETION SYSTEM	Engine speed (RPM)					
	1300*	1800	2400	3000	3600	4150*
GASOLINE ORIGINAL	.295	282	.284	.293	.315	.301
BEAM	.388 / +31.72	.384 / +36.17	.407 / +43.49	.437 / +49.04	.468 / +48.79	.518 / +72.13
A.F.S.	.396 / +34.15	.396 / +40.30	.413 / +45.69	.438 / +49.65	.483 / +53.63	.537 / +78.38
ALGAS	.392 / +32.93	.392 / +39.03	.410 / +44.43	.439 / +49.96	.472 / +49.93	.516 / +71.54
CENTURY	.374 / +26.86	.375 / +33.00	.400 / +40.96	.430 / +46.90	.453 / +43.96	.471 / +56.38
C.F.S.	.398 / +35.06	.434 / +53.95	.455 / +60.20	.473 / +61.56	.488 / +55.05	.481 / +59.65
FUELCON	.421 / +42.71	.410 / +45.39	.423 / +48.94	.490 / +67.24	.497 / +57.78	.496 / +64.78
C.K.	.404 / +36.95	.404 / +43.26	.423 / +48.94	.467 / +59.39	.460 / +46.03	.472 / +56.81
IMPCO	.376 / +27.46	.377 / +33.69	.417 / +46.83	.415 / +41.64	.450 / +42.86	.482 / +60.13

* extrapolated values

Table 6-15: Brake Specific Fuel Consumption
Volume Base

l/hp.h / % vs Gasoline , average values

33% LOAD

CARBURETION SYSTEM	Engine speed (RPM)					
	1300*	1800	2400	3000	3600	4150*
GASOLINE ORIGINAL	.348	.385	.390	.396	.398	
BEAM	.480 / +37.67	.505 / +31.19	.526 / +35.04	.575 / +45.38	.637 / +60.23	
A.F.S.	.512 / +46.92	.498 / +29.56	.545 / +39.87	.593 / +49.90	.679 / +70.77	
ALGAS	.510 / +46.41	.498 / +29.56	.537 / +37.83	.576 / +45.60	.661 / +66.31	
CENTURY	.458 / +31.51	.467 / +21.42	.520 / +33.44	.563 / +42.21	.609 / +53.25	
C.F.S.	.473 / +35.87	.510 / +32.58	.600 / +54.11	.703 / +77.71	.710 / +78.68	
FUELCON	.577 / +65.80	.575 / +49.35	.568 / +45.64	.634 / +60.10	.614 / +54.27	
C.K.	.536 / +54.02	.518 / +34.55	.559 / +43.33	.617 / +55.81	.628 / +57.79	
IMPCO	.475 / +36.49	.492 / +27.79	.515 / +32.05	.545 / +37.63	.625 / +57.04	

* extrapolated values

Table 6-16: Brake Fuel Consumption
Volume Base

$\frac{l/h}{\% \text{ vs Gasoline}}$, average values

10% LOAD

CARBURETION SYSTEM	Engine speed (RPM)					
	1300*	1800	2400	3000	3600	4150*
GASOLINE ORIGINAL	3.44	5.34	6.99	8.87	11.84	
BEAM	3.96 / +15.21	6.05 / +13.21	8.95 / +28.09	12.89 / +45.38	17.74 / +49.84	
A.F.S.	4.03 / +17.03	6.17 / +15.57	9.53 / +36.41	13.12 / +47.90	18.19 / +53.61	
ALGAS	4.05 / +17.81	6.14 / +14.90	9.07 / +29.89	13.02 / +46.79	17.88 / +50.99	
CENTURY	4.44 / +28.99	6.08 / +13.72	9.15 / +31.03	12.75 / +43.76	16.49 / +39.26	
C.F.S.	4.12 / +19.63	6.22 / +16.40	9.17 / +31.29	14.28 / +61.02	18.75 / +58.30	
FUELCON	5.70 / +65.70	7.10 / +32.96	10.83 / +54.94	15.21 / +71.48	17.09 / +44.34	
C.K.	4.30 / +25.00	6.24 / +16.85	9.81 / +40.34	13.83 / +55.92	17.08 / +44.26	
IMPCO	4.59 / +33.43	6.30 / +17.98	9.03 / +29.18	12.83 / +44.64	16.94 / +43.07	

* extrapolated values

This series of tests was conducted at constant loads, at stabilized engine temperature. It can be supposed that tests at low temperatures and under transient conditions of speed can add to the advantage of propane fuel economy. Finally, it can be supposed that the propane carburetion systems will show a 5-25% higher consumption in volumetric units, compared to gasoline. The economical advantage can result from the difference in price - if any - in energy content terms and from the improved life for engine, oil and spark plugs.

The manifold vacuum is given in Table 6-17 and Figure 6-10. The differences in values are determined by the construction of the different mixers on top of the gasoline carburetor body and for IMPCO system by the construction of its own carburetor.

In Table 6-18 and Figure 6-11 are presented the values of spark advance for different speeds and loads. This is total advance, including the static timing, centrifugal advance and vacuum advance determined by the values of manifold vacuum and the lay-out of each system, with distributor vacuum ported or not.

The relative throttle position is presented in Table 6-19. The differences are determined by the internal resistance to flow of different systems.

Table 6-17: Manifold vacuum in Hg., average values

LOAD(%)	SYSTEM	Engine speed (RPM)						
		600	1300	1800	2400	3000	3600	4150
100	GASOL.		0.50	0.55	1.00	1.15	1.50	1.70
	BEAM		0.55	0.90	1.50	2.35	3.05	3.95
	A.F.S.		0.35	0.60	0.95	1.45	1.88	2.35
	ALGAS		1.00	1.20	1.50	1.90	2.25	2.70
	CENTURY		0.58	0.80	1.20	1.55	2.05	2.50
	C.F.S.		0.70	0.95	1.40	1.85	2.40	2.90
	FUELCON		0.53	0.70	1.05	1.48	2.03	2.45
	C.K.		0.40	0.60	1.03	1.58	2.20	2.70
	IMPCO		0.50	0.50	0.60	0.70	0.95	1.10
66	GASOL.		4.80	5.05	5.10	5.15	5.35	5.65
	BEAM		6.75	7.20	7.15	8.15	8.30	8.75
	A.F.S.		8.00	7.75	7.65	8.25	8.80	9.25
	ALGAS		6.60	7.20	7.75	7.95	8.10	8.90
	CENTURY		4.70	4.60	4.80	6.85	8.00	8.75
	C.F.S.		7.25	7.95	8.35	8.88	10.10	9.95
	FUELCON		7.30	7.95	8.05	8.50	9.15	9.55
	C.K.		7.55	7.95	8.65	9.15	9.75	10.10
	IMPCO		2.50	2.65	3.05	3.30	3.80	4.00
33	GASOL.		12.45	12.50	12.10	12.60	12.90	12.30
	BEAM		13.10	13.85	14.10	14.60	15.35	-
	A.F.S.		14.75	14.65	15.20	15.10	15.25	-
	ALGAS		13.50	14.20	14.60	15.10	14.65	-
	CENTURY		13.35	13.30	11.85	12.05	13.25	-
	C.F.S.		13.15	14.55	15.30	15.40	16.10	-
	FUELCON		14.60	15.00	15.10	15.20	15.50	-
	C.K.		14.20	14.95	15.45	15.65	15.75	-
	IMPCO		12.10	12.30	11.10	9.30	9.35	9.25
~10	GASOL.	19.25	17.90	17.20	16.55	16.40	15.75	14.40
	BEAM	18.70	18.20	18.60	18.00	18.05	16.70	-
	A.F.S.	18.15	19.38	19.65	19.05	18.30	17.10	-
	ALGAS	19.15	19.25	19.30	18.80	17.95	17.15	-
	CENTURY	19.05	19.90	19.60	17.30	16.25	14.95	-
	C.F.S.	19.25	18.90	18.25	18.60	18.50	17.60	-
	FUELCON	18.63	19.40	19.75	18.80	18.50	18.25	-
	C.K.	18.95	19.35	19.60	19.10	18.60	17.70	-
	IMPCO	18.70	18.10	17.85	16.15	13.70	11.70	-

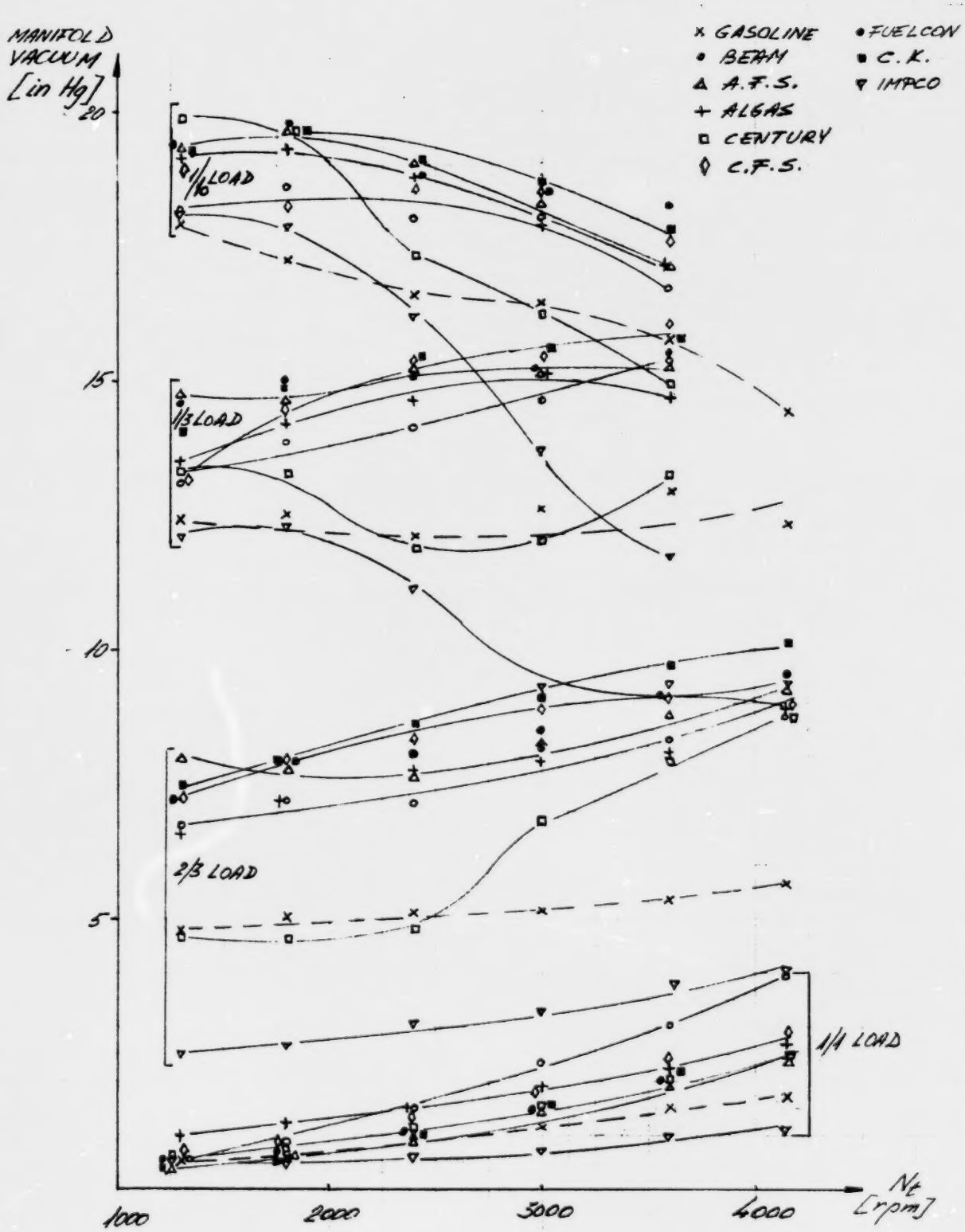


Figure 6-10: Comparison of manifold vacuum.

Table 6-18: Spark advance degrees, average values

LOAD (%)	SYSTEM	Engine speed (RPM)						
		600	1300	1800	2400	3000	3600	4150
100	GASOL.		9.50	14.10	16.00	18.50	20.50	-
	BEAM		15.50	19.00	24.00	24.50	25.50	-
	A.F.S.		17.00	19.25	23.50	24.00	24.50	-
	ALGAS		17.00	19.50	24.50	25.25	25.75	-
	CENTURY		16.00	17.50	22.00	22.50	23.00	-
	C.F.S.		15.00	17.25	22.25	23.00	23.00	-
	FUELCON		14.50	17.75	22.00	22.50	22.50	-
	C.K.		15.50	17.50	21.25	22.25	22.75	-
	IMPCO		17.50	20.00	24.50	26.00	26.50	-
66	GASOL.		17.75	21.50	23.50	28.00	30.50	-
	BEAM		30.00	35.50	39.50	42.00	45.00	-
	A.F.S.		34.25	38.50	40.75	42.75	44.75	-
	ALGAS		30.50	36.75	42.00	44.25	44.75	-
	CENTURY		22.00	25.00	26.00	36.75	41.00	-
	C.F.S.		31.50	35.25	41.25	45.75	45.75	-
	FUELCON		31.50	36.75	40.75	42.25	46.75	-
	C.K.		33.00	37.00	42.75	45.75	46.00	-
	IMPCO		20.50	25.50	28.50	31.00	34.00	-
33	GASOL.		33.75	38.00	41.50	43.70	45.50	-
	BEAM		39.50	44.00	48.00	48.25	51.00	-
	A.F.S.		39.50	43.75	46.75	47.50	49.00	-
	ALGAS		41.75	45.00	48.25	49.75	50.00	-
	CENTURY		39.25	41.25	45.00	46.00	46.75	-
	C.F.S.		38.25	41.00	45.00	47.25	47.25	-
	FUELCON		37.50	42.75	45.50	46.25	47.00	-
	C.K.		40.00	42.00	45.50	45.50	46.00	-
	IMPCO		38.50	40.75	43.50	44.00	44.50	-
~10	GASOL.	19.50	31.50	38.75	41.25	44.00	45.25	-
	BEAM	12.00	22.00	44.00	48.00	48.00	48.00	-
	A.F.S.	12.00	17.50	44.00	48.00	47.75	-	-
	ALGAS	12.00	20.75	44.25	49.50	50.00	-	-
	CENTURY	12.00	15.25	41.75	46.00	46.50	-	-
	C.F.S.	12.00	20.25	41.25	46.00	47.00	-	-
	FUELCON	12.00	15.50	42.75	46.25	46.75	47.00	-
	C.K.	12.00	16.25	41.75	45.50	45.75	47.00	-
	IMPCO	12.00	12.00	35.00	42.25	44.50	45.00	-

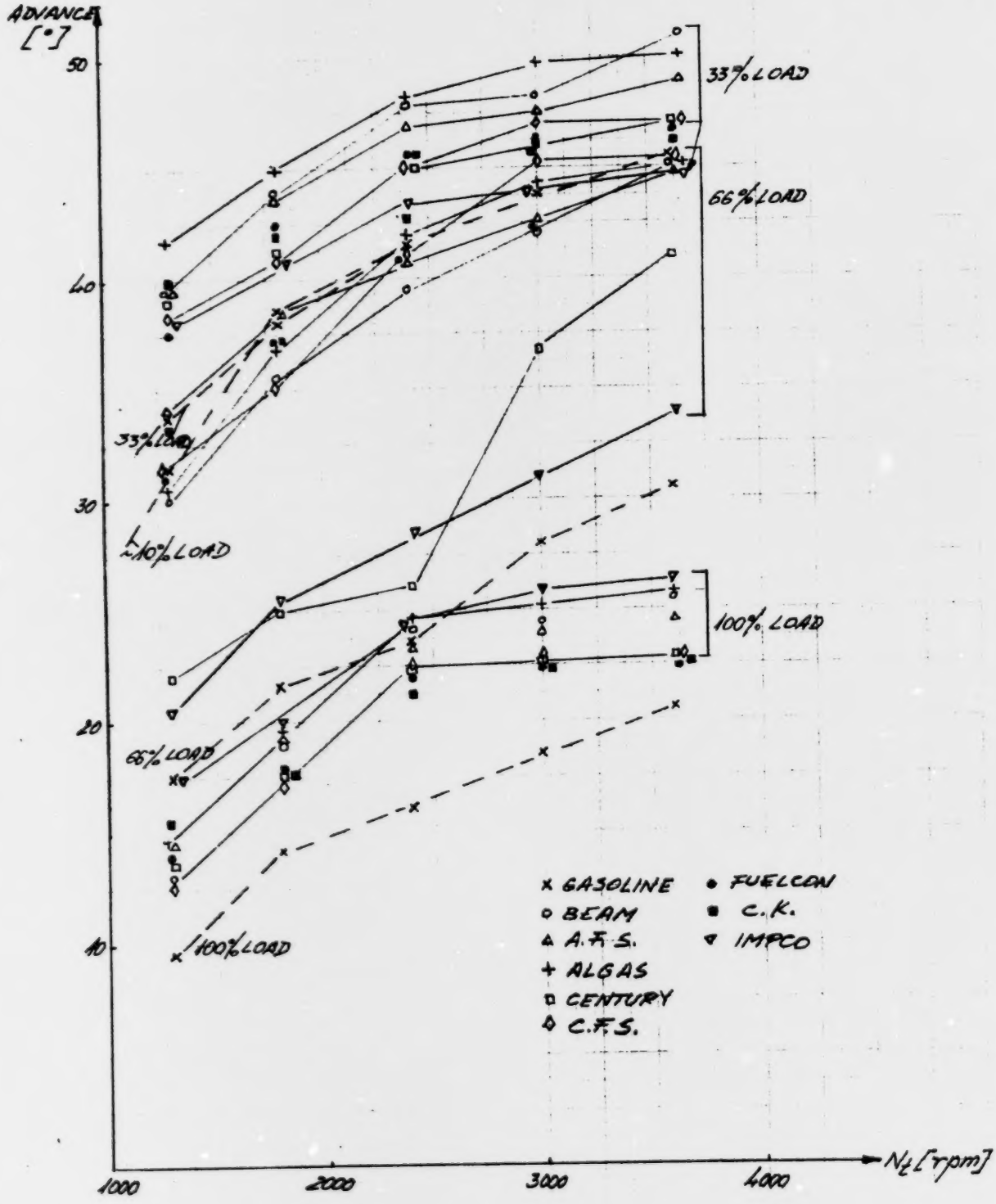


Figure 6-11:Comparison of spark advance curves

Table 6-19: Throttle position
0 - 1000 for idle - WOT, average values

LOAD (%)	SYSTEM	Engine speed (RPM)						
		600	1300	1800	2400	3000	3600	4150
66	GASOL.		237	300	360	422	450	489
	BEAM		281	349	392	477	529	577
	A.F.S.		299	334	408	441	499	515
	ALGAS		278	330	331	449	482	502
	CENTURY		266	327	403	402	423	429
	C.F.S.		234	279	326	352	413	436
	FUELCON		228	306	368	409	422	487
	C.K.		226	266	322	255	365	380
	IMPCO		180	223	253	300	338	343
33	GASOL.		127	172	232	265	279	-
	BEAM		188	238	290	332	372	-
	A.F.S.		193	224	272	323	355	-
	ALGAS		164	210	263	305	328	-
	CENTURY		134	179	260	299	307	-
	C.F.S.		163	190	222	261	300	-
	FUELCON		136	204	248	290	294	-
	C.K.		102	160	203	246	260	-
	IMPCO		088	122	168	224	247	-
~10	GASOL.	000	080	123	182	210	246	-
	BEAM	000	081	128	225	279	334	-
	A.F.S.	000	134	157	209	260	318	-
	ALGAS	000	099	141	195	252	287	-
	CENTURY	000	074	104	183	242	283	-
	C.F.S.	000	106	144	175	215	300	-
	FUELCON	000	083	129	187	229	260	-
	C.K.	000	053	095	147	189	215	-
	IMPCO	000	048	073	116	164	217	-

In Table 6-20 and Figure 6-12 are presented the average exhaust gas temperatures. At WOT the temperature with propane is generally higher (up to 89°F) and at partial loads lower (down to 116°F) than for gasoline. The correlation between exhaust temperature and A/F ratio for different loads and speeds is graphically presented in Figures 6-13 to 6-15. The highest temperature is obtained in the region of stoichiometric mixtures. A reduction of 50-80°F is obtained if the mixtures are far enough from stoichiometric.

The distribution of exhaust gas temperature among cylinders can be found in Tables 6-21 to 6-23 and Figures 6-16 to 6-18. The different patterns of temperature distribution are determined by the design of different carburetion systems. The BEAM system, for instance, with the fuel supply centered on one side of the venturi, favours the three cylinders on the opposite side (nos. 2, 4 and 6), with resultant higher temperatures in those cylinders.

HC emission is presented in Table 6-24 and Figure 6-19. For propane systems the HC concentration is higher than for gasoline (both are measured before the catalytic converter). As for all other emissions to follow, the large spread of values is determined by the air-fuel ratio of every system at each load and speed. The concentration of HC increases for richer mixture.

CO emission is given in Table 6-25 and Figure 6-20.

Table 6-20: Exhaust gas temperature °F, average values

LOAD(%)	SYSTEM	Engine speed (RPM)						
		600	1300	1800	2400	3000	3600	4150
100	GASOL.		1039	1167	1283	1308	1370	1413
	BEAM		1035	1171	1278	1310	1372	1409
	A.F.S.		1012	1195	1311	1350	1414	1497
	ALGAS		1022	1166	1300	1352	1409	1480
	CENTURY		1008	1221	1321	1348	1410	1473
	C.F.S.		1017	1179	1307	1342	1409	1470
	FUELCON		1021	1151	1261	1292	1344	1388
	C.K.		1047	1190	1306	1328	1418	1502
	IMPCO		1030	1144	1264	1280	1337	1393
66	GASOL.		963	1084	1204	1224	1289	1330
	BEAM		931	1046	1153	1192	1253	1317
	A.F.S.		904	1055	1183	1209	1278	1375
	ALGAS		926	1062	1164	1195	1266	1313
	CENTURY		947	1053	1181	1185	1276	1334
	C.F.S.		942	1043	1168	1210	1289	1350
	FUELCON		871	1038	1172	1168	1237	1286
	C.K.		924	1065	1178	1208	1278	1322
	IMPCO		877	1002	1114	1184	1238	1314
33	GASOL.		797	962	1073	1093	1169	-
	BEAM		777	901	1027	1049	1127	-
	A.F.S.		758	909	1065	1089	1162	-
	ALGAS		785	922	1058	1072	1158	-
	CENTURY		782	900	1027	1034	1106	-
	C.F.S.		774	939	1048	1053	1130	-
	FUELCON		746	879	1018	1065	1150	-
	C.K.		777	920	1047	1074	1161	-
	IMPCO		766	877	1007	1038	1117	-
~10	GASOL.		725	889	1045	1060	1140	-
	BEAM		686	773	921	952	1068	-
	A.F.S.		694	784	930	984	1110	-
	ALGAS		695	771	911	1000	1100	-
	CENTURY		690	794	932	965	1056	-
	C.F.S.		654	775	933	968	1048	-
	FUELCON		620	791	890*	937	1071	-
	C.K.		663	757	907	1001	1090	-
	IMPCO		726	776	912	963	1082	-

- measured 10 in. after the union of the two exhaust pipes of the engine, at the end of the 3 min. test periods

- 3000, 3600 and 4150 rpm tests with forced ventilation of exhaust manifolds

* extrapolated values

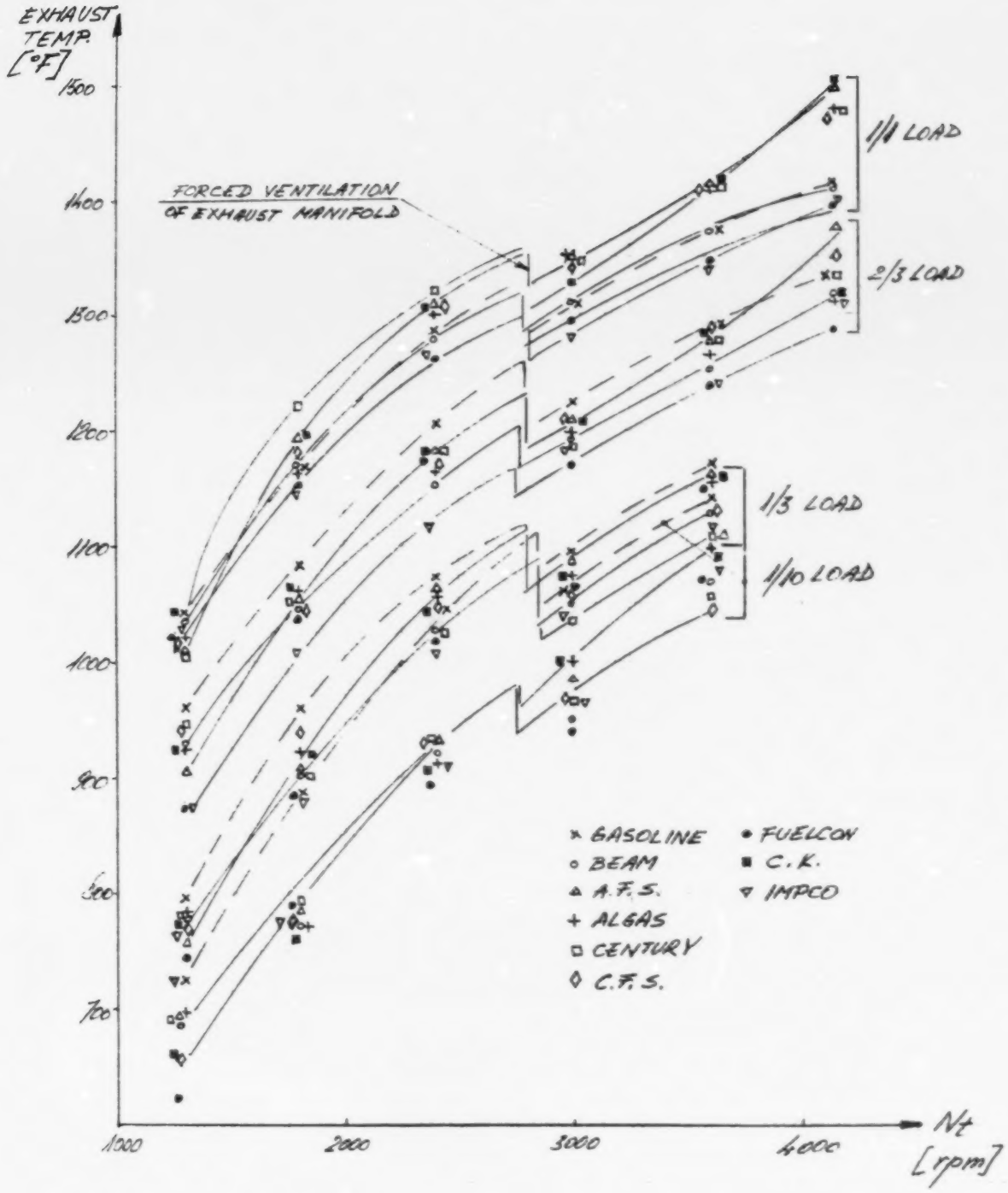


Figure 6-12: Comparison of exhaust gas temperatures

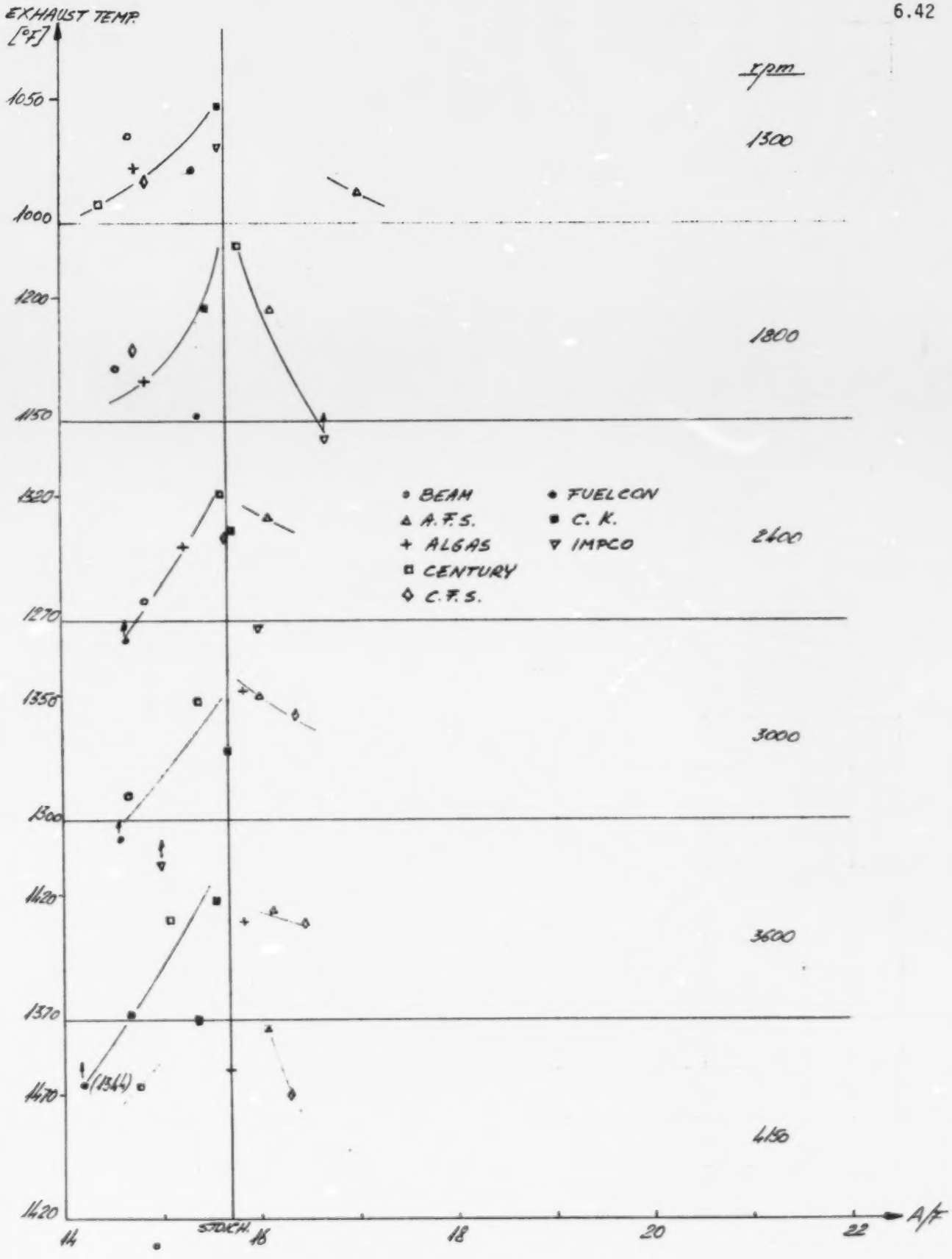


Figure 6-13: Correlation between exhaust gas temperature and A/F ratio 100% load

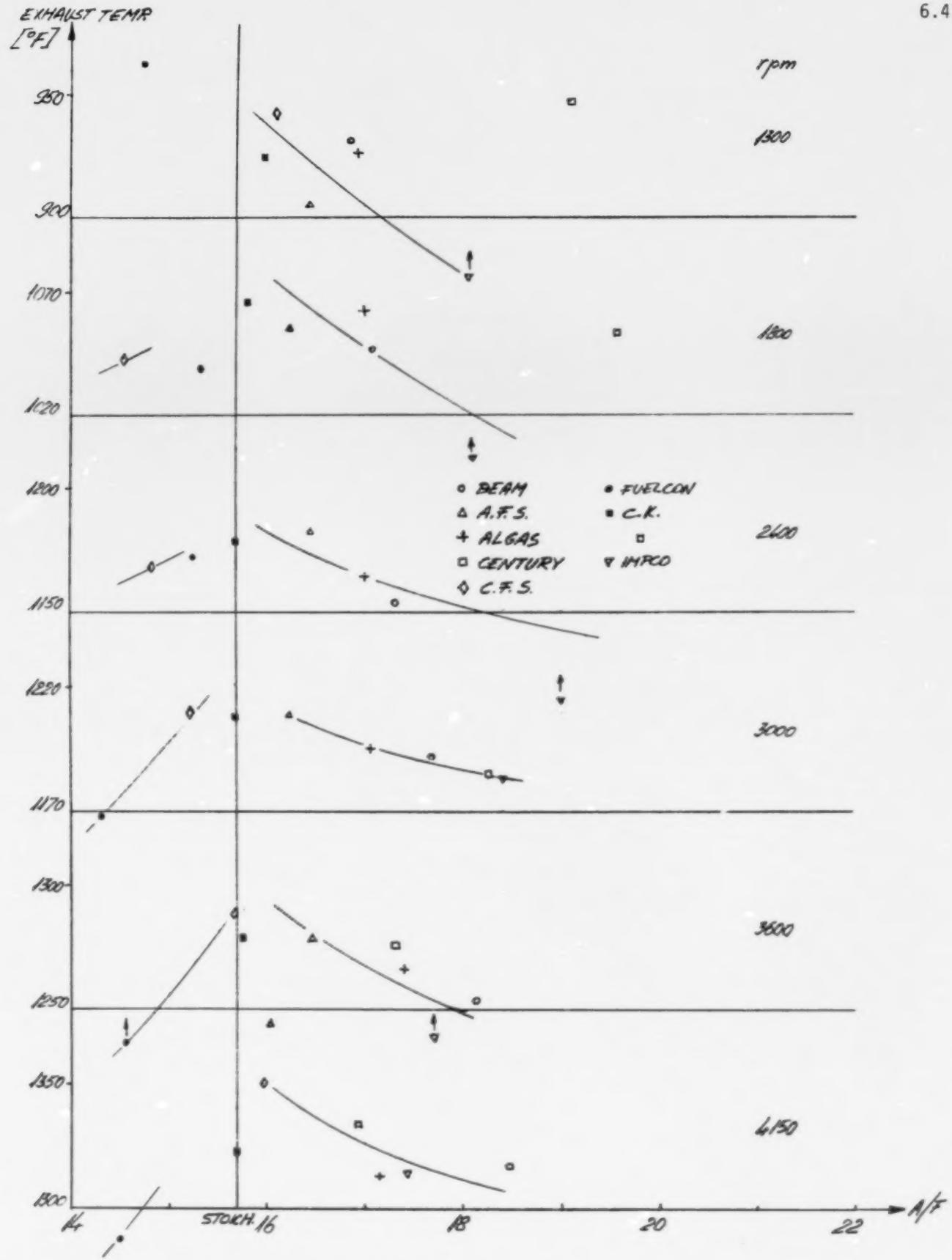


Figure 6-14: Correlation between exhaust gas temperature and A/F ratio 66% load

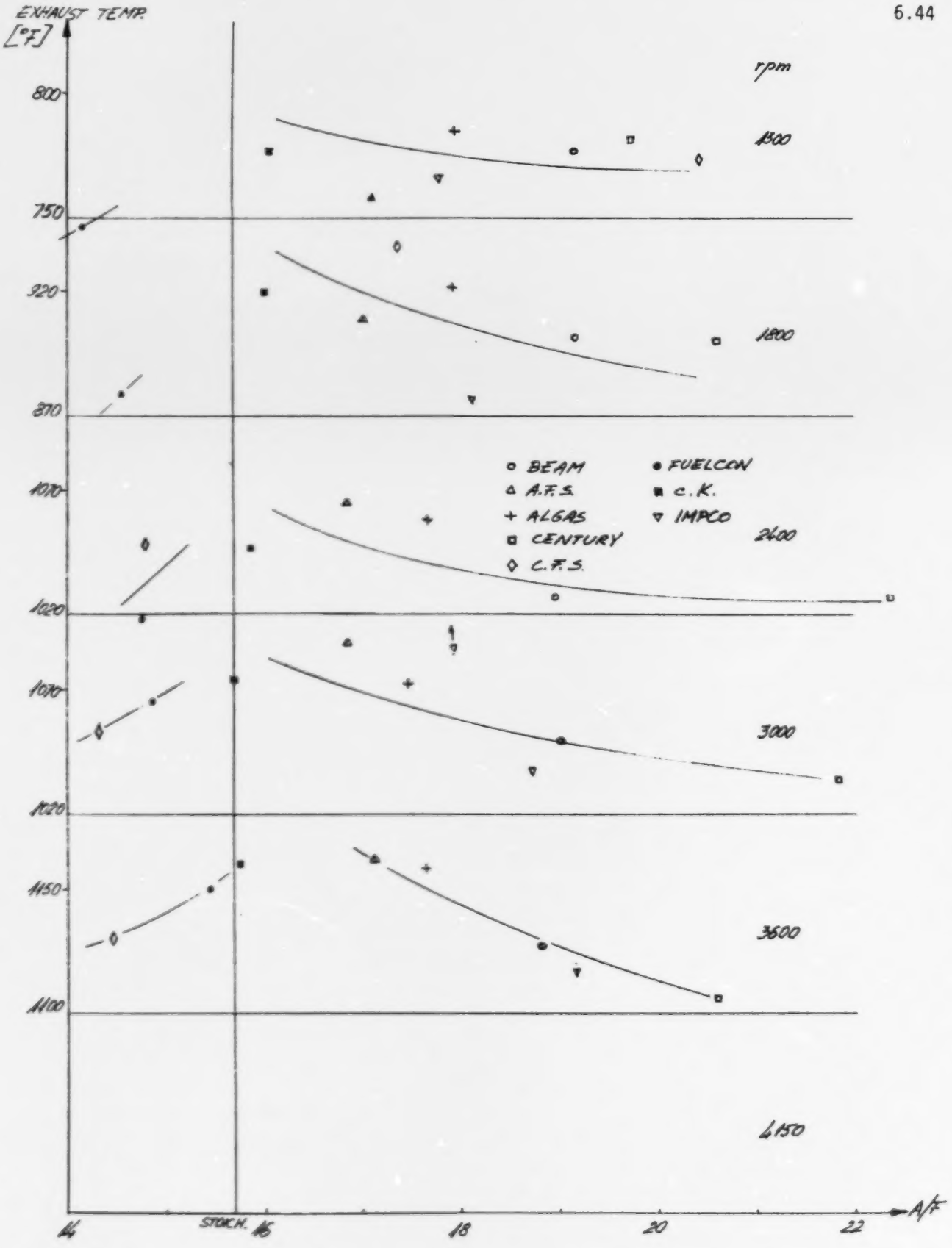


Figure 6-15: Correlation between exhaust gas temperature and A/F Ratio 33% load

Table 6-21: Distribution of cylinders exhaust gas temperatures - ^{o}F
Engine speed: 1300 rpm* (average values)

LOAD(%)	EQUIPMENT	Cylinder no.					
		1	2	3	4	5	6
100	GASOL.	1110	1063	1035	980	1188	1130
	BEAM	1109	1068	1077	1082	1137	1142
	A.F.S.	1046	1046	1053	1049	1063	1083
	ALGAS	1054	1078	1058	1091	1084	1122
	CENTURY	1043	1048	1039	1062	1058	1095
	C.F.S.	1053	1060	1043	1049	1076	1114
	FUELCON	1086	1071	1078	1069	1093	1131
	C.K.	1091	1079	1083	1070	1102	1148
	IMPCO	1065	1084	1073	1094	1121	1144
66	GASOL.	1074	1092	1058	1016	1137	1118
	BEAM	975	1054	972	1062	1001	1063
	A.F.S.	1007	1044	1002	1040	1028	1042
	ALGAS	1006	1036	1005	1033	1026	1049
	CENTURY	1002	1013	1003	1018	1017	1026
	C.F.S.	1018	1047	1016	1015	1045	1065
	FUELCON	1000	998	994	983	1014	1024
	C.K.	1028	1058	1021	1042	1043	1082
	IMPCO	1013	1000	1005	994	1054	1021
33	GASOL.	1008	1032	959	963	1058	1021
	BEAM	948	990	911	967	952	945
	A.F.S.	990	1005	954	970	995	955
	ALGAS	966	1001	933	984	970	972
	CENTURY	957	962	921	941	959	927
	C.F.S.	948	963	905	920	952	934
	FUELCON	958	964	924	927	959	935
	C.K.	1012	1017	970	977	998	983
	IMPCO	1002	974	971	949	1042	947
~10	GASOL.	1090	1086	987	968	1156	1040
	BEAM	1001	1002	971	978	1040	996
	A.F.S.	1012	1028	972	1010	1052	995
	ALGAS	993	1012	968	1002	1016	993
	CENTURY	1005	1013	960	1009	1009	991
	C.F.S.	1009	995	949	964	1037	982
	FUELCON	926	946	896	942	941	928
	C.K.	1046	1055	1018	1045	1039	1044
	IMPCO	1102	1115	1064	1087	1162	1066

- measured in the middle of the exhaust manifold ports, at 1 in. from exhaust valve steam

* extrapolated values

Table 6-22: Distribution of cylinders exhaust gas temperatures - °F
Engine speed: 2400 rpm (average values)

LOAD(%)	EQUIPMENT	Cylinder no.					
		1	2	3	4	5	6
100	GASOL.	1271	1222	1228	1144	1362	1297
	BEAM	1304	1263	1320	1262	1324	1325
	A.F.S.	1284	1310	1261	1299	1286	1324
	ALGAS	1264	1301	1252	1290	1264	1324
	CENTURY	1272	1308	1260	1287	1288	1353
	C.F.S.	1276	1281	1243	1256	1283	1345
	FUELCON	1247	1246	1223	1230	1252	1282
	C.K.	1285	1282	1260	1261	1282	1335
	IMPCO	1262	1243	1234	1257	1287	1295
66	GASOL.	1239	1246	1212	1204	1311	1274
	BEAM	1143	1248	1136	1253	1145	1257
	A.F.S.	1208	1251	1197	1247	1208	1255
	ALGAS	1191	1207	1184	1208	1191	1225
	CENTURY	1159	1183	1157	1176	1184	1223
	C.F.S.	1189	1214	1175	1192	1192	1246
	FUELCON	1206	1220	1191	1207	1206	1250
	C.K.	1219	1241	1207	1225	1221	1258
	IMPCO	1131	1144	1123	1142	1169	1162
33	GASOL.	1172	1201	1176	1179	1272	1224
	BEAM	1111	1179	1095	1177	1129	1172
	A.F.S.	1198	1219	1177	1207	1167	1210
	ALGAS	1182	1183	1162	1174	1182	1180
	CENTURY	1082	1106	1077	1089	1109	1129
	C.F.S.	1170	1172	1140	1141	1164	1185
	FUELCON	1159	1163	1132	1142	1154	1172
	C.K.	1201	1216	1169	1184	1196	1212
	IMPCO	1149	1149	1143	1127	1207	1153
~10	GASOL.	1210	1242	1213	1236	1310	1283
	BEAM	1112	1161	1069	1153	1126	1156
	A.F.S.	1183	1176	1137	1165	1171	1178
	ALGAS	1138	1159	1094	1157	1143	1166
	CENTURY	1111	1132	1076	1097	1130	1155
	C.F.S.	1148	1156	1097	1130	1150	1183
	FUELCON	1140	1115	1091	1092	1127	1111
	C.K.	1177	1180	1127	1155	1175	1175
	IMPCO	1149	1143	1126	1140	1207	1142

Table 6-23: Distribution of cylinders exhaust gas temperatures - ^{o}F
Engine speed: 3600 rpm (average values)

LOAD(%)	EQUIPMENT	Cylinder no.					
		1	2	3	4	5	6
100	GASOL.	1392	1340	1365	1240	1501	1399
	BEAM	1467	1413	1476	1397	1482	1448
	A.F.S.	1434	1461	1407	1447	1435	1445
	ALGAS	1446	1497	1409	1465	1431	1462
	CENTURY	1391	1463	1353	1431	1399	1462
	C.F.S.	1407	1456	1379	1417	1405	1457
	FUELCON	1394	1360	1363	1315	1389	1351
	C.K.	1448	1435	1384	1385	1416	1428
	IMPCO	1368	1356	1361	1348	1444	1350
66	GASOL.	1329	1360	1298	1301	1411	1348
	BEAM	1263	1375	1234	1365	1251	1354
	A.F.S.	1358	1378	1329	1363	1327	1355
	ALGAS	1316	1363	1299	1354	1314	1349
	CENTURY	1330	1361	1309	1329	1325	1345
	C.F.S.	1364	1384	1336	1343	1347	1370
	FUELCON	1323	1316	1289	1281	1299	1287
	C.K.	1357	1381	1324	1344	1340	1348
	IMPCO	1278	1364	1278	1341	1337	1327
33	GASOL.	1294	1322	1263	1241	1379	1294
	BEAM	1239	1322	1199	1305	1216	1291
	A.F.S.	1314	1345	1272	1295	1302	1314
	ALGAS	1306	1325	1268	1303	1301	1303
	CENTURY	1220	1254	1170	1209	1222	1237
	C.F.S.	1287	1306	1245	1264	1279	1285
	FUELCON	1324	1339	1276	1296	1309	1301
	C.K.	1333	1350	1283	1301	1308	1304
	IMPCO	1243	1272	1228	1242	1305	1229
~10	GASOL.	1311	1438	1301	1263	1399	1311
	BEAM	1243	1313	1200	1300	1232	1291
	A.F.S.	1331	1348	1284	1330	1317	1333
	ALGAS	1329	1313	1271	1291	1317	1296
	CENTURY	1203	1243	1170	1204	1222	1233
	C.F.S.	1260	1295	1197	1252	1258	1288
	FUELCON	1317	1327	1258	1280	1315	1306
	C.K.	1326	1338	1261	1294	1321	1313
	IMPCO	1250	1274	1231	1240	1313	1229

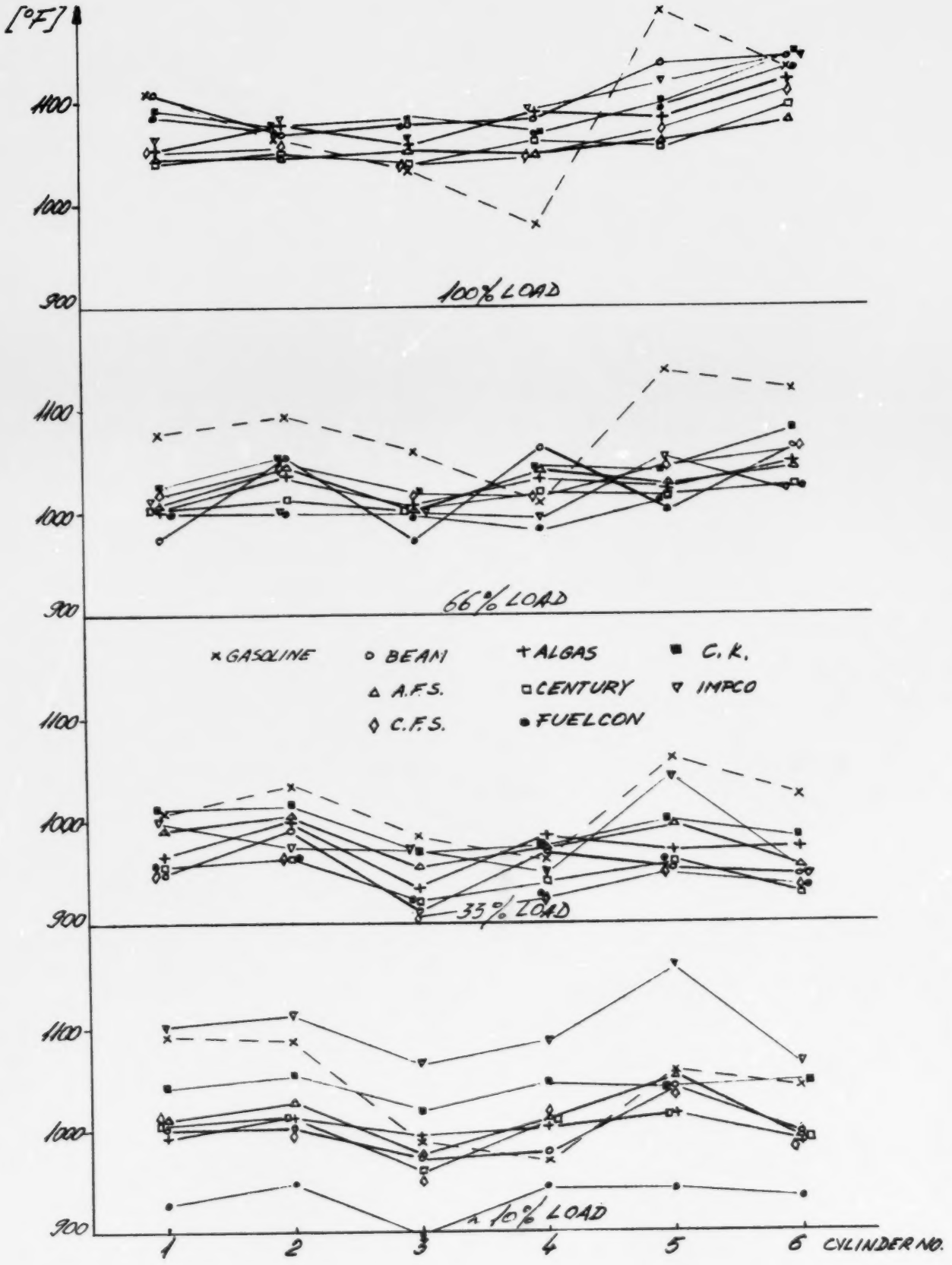


Figure 6-16: Temperature of exhaust gas from each cylinder at 1300 rpm.

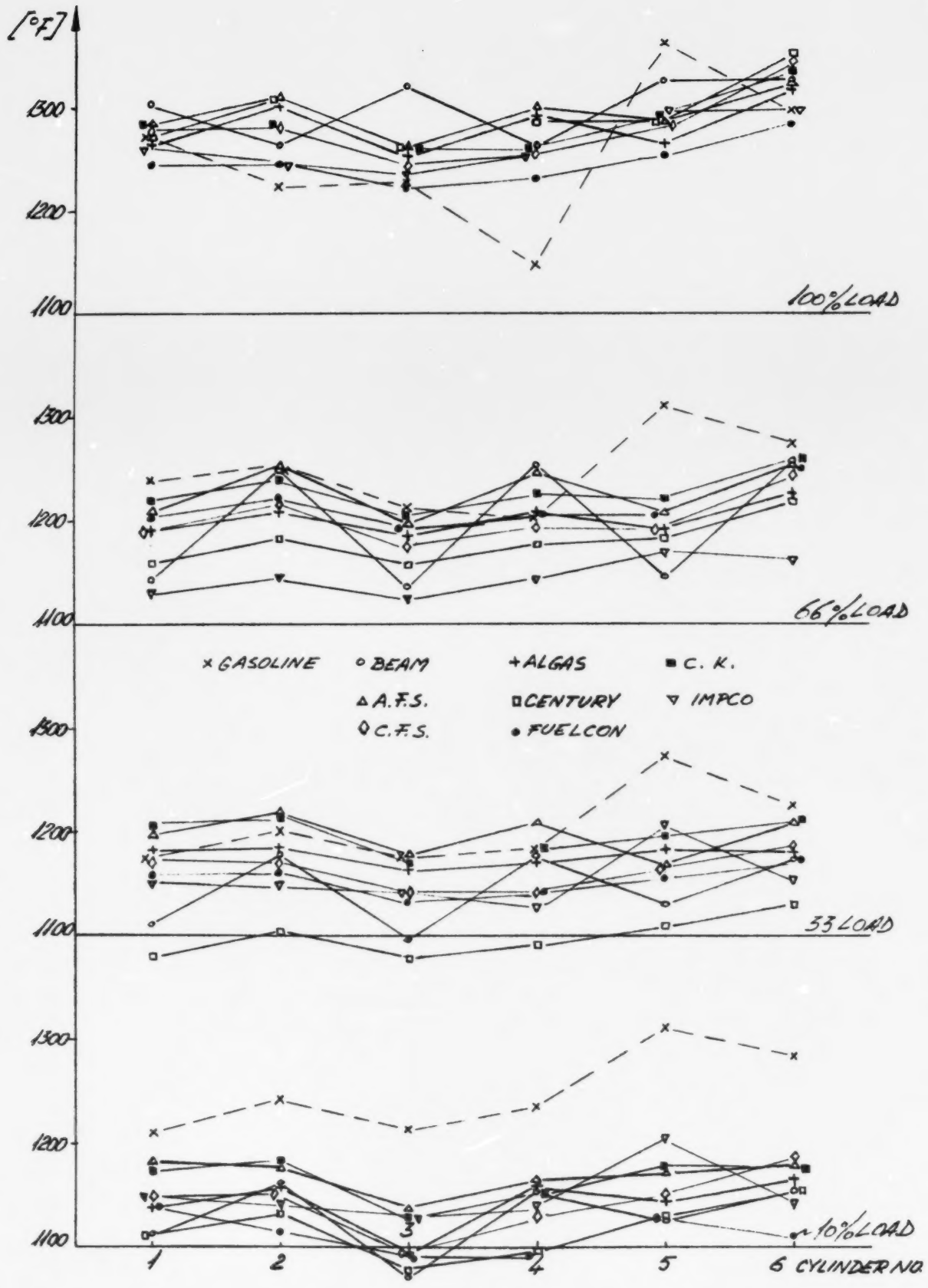


Figure 6-17: Temperature of exhaust gas from each cylinder at 2400 rpm.

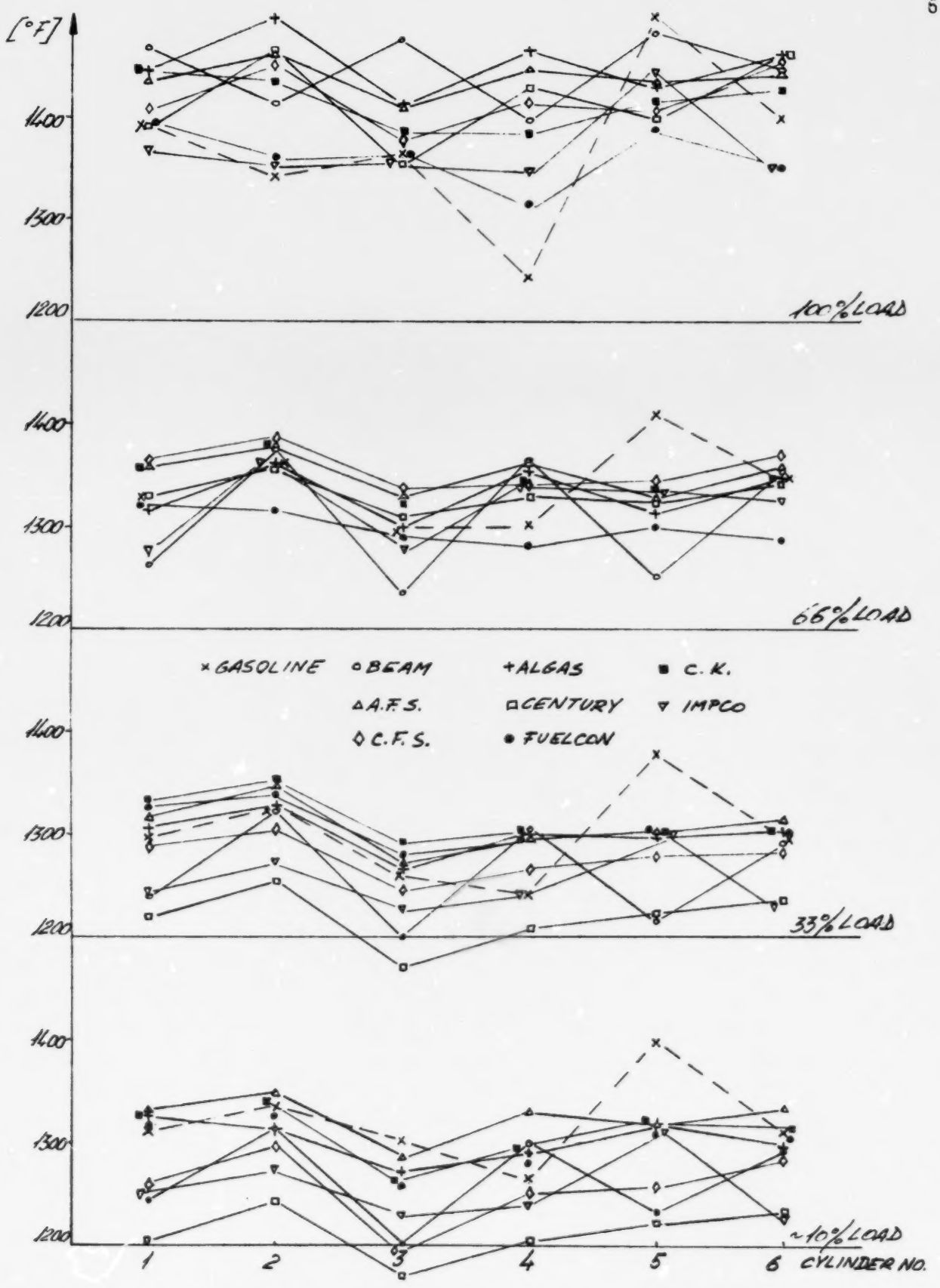


Figure 6-18: Temperature of exhaust gas from each cylinder at 3600 rpm.

Table 6-24: HC Emission
PPM, average values
(before catalytic converter; gasoline with emission controls, LPG without)

LOAD(%)	SYSTEM	Engine speed (RPM)						
		600	1300	1800	2400	3000	3600	4150
100	GASOL.		97	117	73	63	50	52
	BEAM		215	188	133	110	84	70
	A.F.S.		130	101	73	45	29	15
	ALGAS		223	205	145	71	44	38
	CENTURY		170	130	111	99	86	65
	C.F.S.		195	185	106	34	17	12
	FUELCON		210	178	154	121	107	76
	C.K.		163	128	80	45	30	20
	IMPCO		143	43	37	68	55	38
66	GASOL.		60	47	25	19	15	12
	BEAM		178	127	76	63	51	35
	A.F.S.		176	134	65	60	42	39
	ALGAS		170	133	71	53	35	26
	CENTURY		130	67	41	50	42	34
	C.F.S.		210	215	164	127	80	48
	FUELCON		220	210	159	158	133	117
	C.K.		180	155	115	93	73	56
	IMPCO		110	75	19	23	23	20
33	GASOL.		90	52	28	23	15	-
	BEAM		180	125	71	65	54	-
	A.F.S.		173	122	74	54	38	-
	ALGAS		180	117	71	56	38	-
	CENTURY		163	120	114	85	48	-
	C.F.S.		173	122	178	166	143	-
	FUELCON		225	230	190	155	96	-
	C.K.		185	140	105	99	75	-
	IMPCO		109	70	41	32	25	-
~10	GASOL.	627	113	80	26	16	16	-
	BEAM	295	213	110	58	66	50	-
	A.F.S.	255	83	75	50	47	31	-
	ALGAS	340	98	82	55	47	35	-
	CENTURY	280	171	71	108	107	79	-
	C.F.S.	330	117	120	50	153	158	-
	FUELCON	390	360	260	205	184	103	-
	C.K.	250	75	93	88	80	63	-
	IMPCO	183	29	25	30	35	23	-

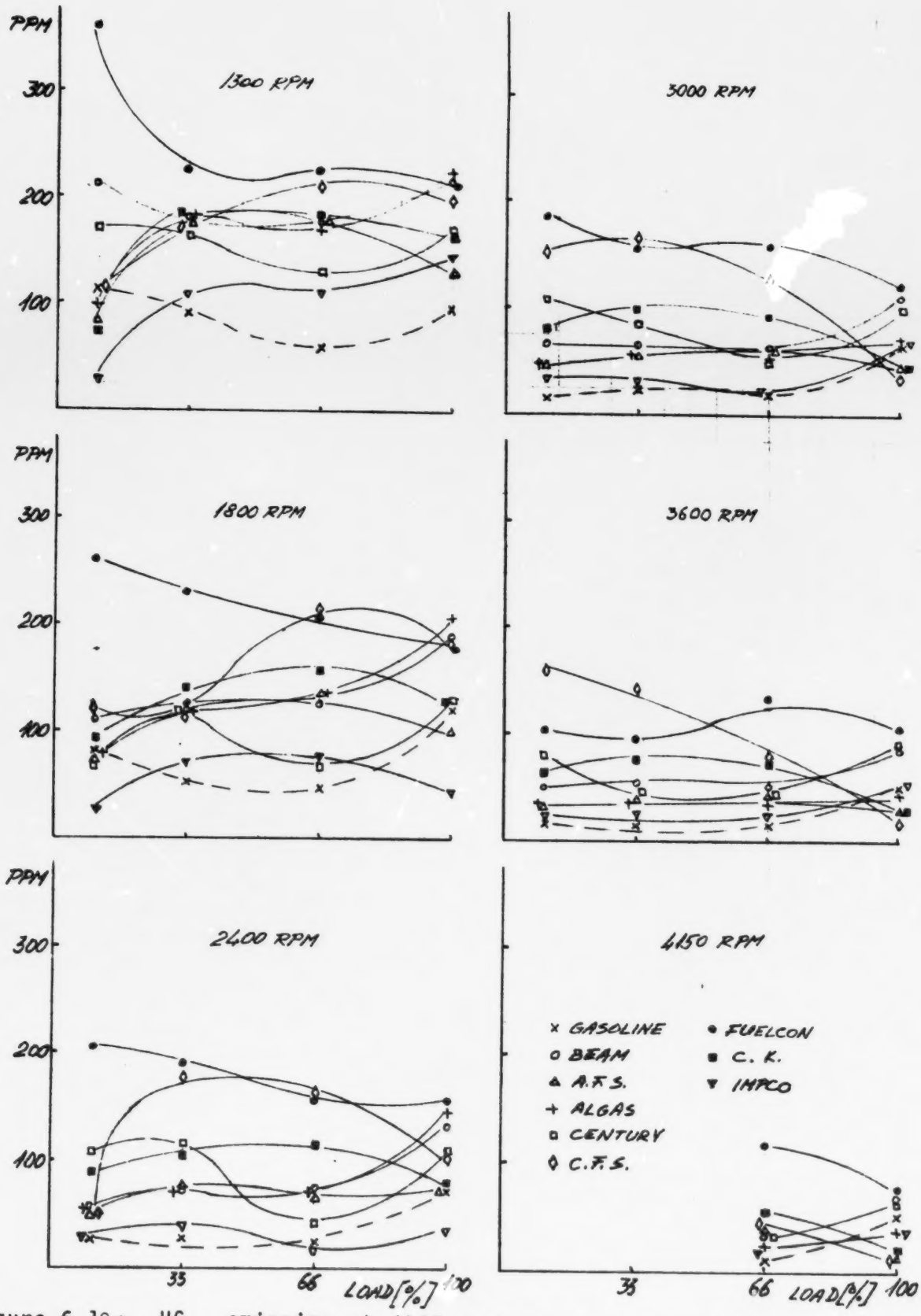


Figure 6-19: HC - emission at different loads and speeds; before catalytic converter(gasoline with emission-controls, propane without)

Table 6-25: CO Emission
%, average values
(before catalytic converter; gasoline with emission controls, propane without)

LOAD (%)	SYSTEM	Engine speed (RPM)						
		600	1300	1800	2400	3000	3600	4150
100	GASOL.		2.37	2.93	3.02	3.05	3.25	3.52
	BEAM		2.15	2.50	2.05	2.35	2.30	1.86
	A.F.S.		0.08	0.09	0.11	0.14	0.23	0.19
	ALGAS		2.00	1.75	1.04	0.34	0.38	0.53
	CENTURY		3.18	0.24	0.64	1.09	1.58	2.07
	C.F.S.		2.55	1.98	0.55	0.11	0.10	0.13
	FUELCON		1.04	0.68	2.12	2.35	3.10	3.15
	C.K.		0.95	0.85	0.64	0.80	1.09	1.27
	IMPCO		0.93	0.07	0.26	1.72	2.13	2.48
66	GASOL.		0.09	0.11	0.10	0.11	0.10	0.10
	BEAM		0.12	0.10	0.09	0.09	0.10	0.12
	A.F.S.		0.09	0.10	0.09	0.15	0.13	0.29
	ALGAS		0.44	0.08	0.09	0.09	0.10	0.10
	CENTURY		0.10	0.10	0.10	0.10	0.11	0.12
	C.F.S.		0.69	2.63	1.92	1.19	0.47	0.25
	FUELCON		2.30	0.99	0.98	2.90	2.38	2.45
	C.K.		0.21	0.30	0.47	0.49	0.51	0.57
	IMPCO		0.05	0.07	0.05	0.06	0.06	0.07
33	GASOL.		0.09	0.11	0.13	0.12	0.12	-
	BEAM		0.09	0.09	0.11	0.10	0.11	-
	A.F.S.		0.10	0.11	0.15	0.14	0.13	-
	ALGAS		0.47	0.10	0.11	0.12	0.11	-
	CENTURY		0.09	0.10	0.11	0.11	0.12	-
	C.F.S.		0.08	0.11	2.38	3.03	2.80	-
	FUELCON		3.53	2.60	2.15	1.85	0.62	-
	C.K.		0.25	0.33	0.38	0.54	0.47	-
	IMPCO		0.05	0.07	0.06	0.07	0.08	-
~10	GASOL.	0.18	0.17	0.20	0.18	0.15	0.13	-
	BEAM	1.60	0.12	0.12	0.13	0.12	0.13	-
	A.F.S.	1.10	0.12	0.13	0.14	0.17	0.14	-
	ALGAS	2.25	0.11	0.12	0.13	0.13	0.12	-
	CENTURY	0.98	2.32	0.12	0.12	0.12	0.13	-
	C.F.S.	1.58	0.10	0.10	0.12	2.33	3.63	-
	FUELCON	0.28	7.20	5.10	2.95	3.33	1.04	-
	C.K.	0.13	0.09	0.16	0.36	0.45	0.45	-
	IMPCO	1.73	0.08	0.08	0.08	0.07	0.08	-

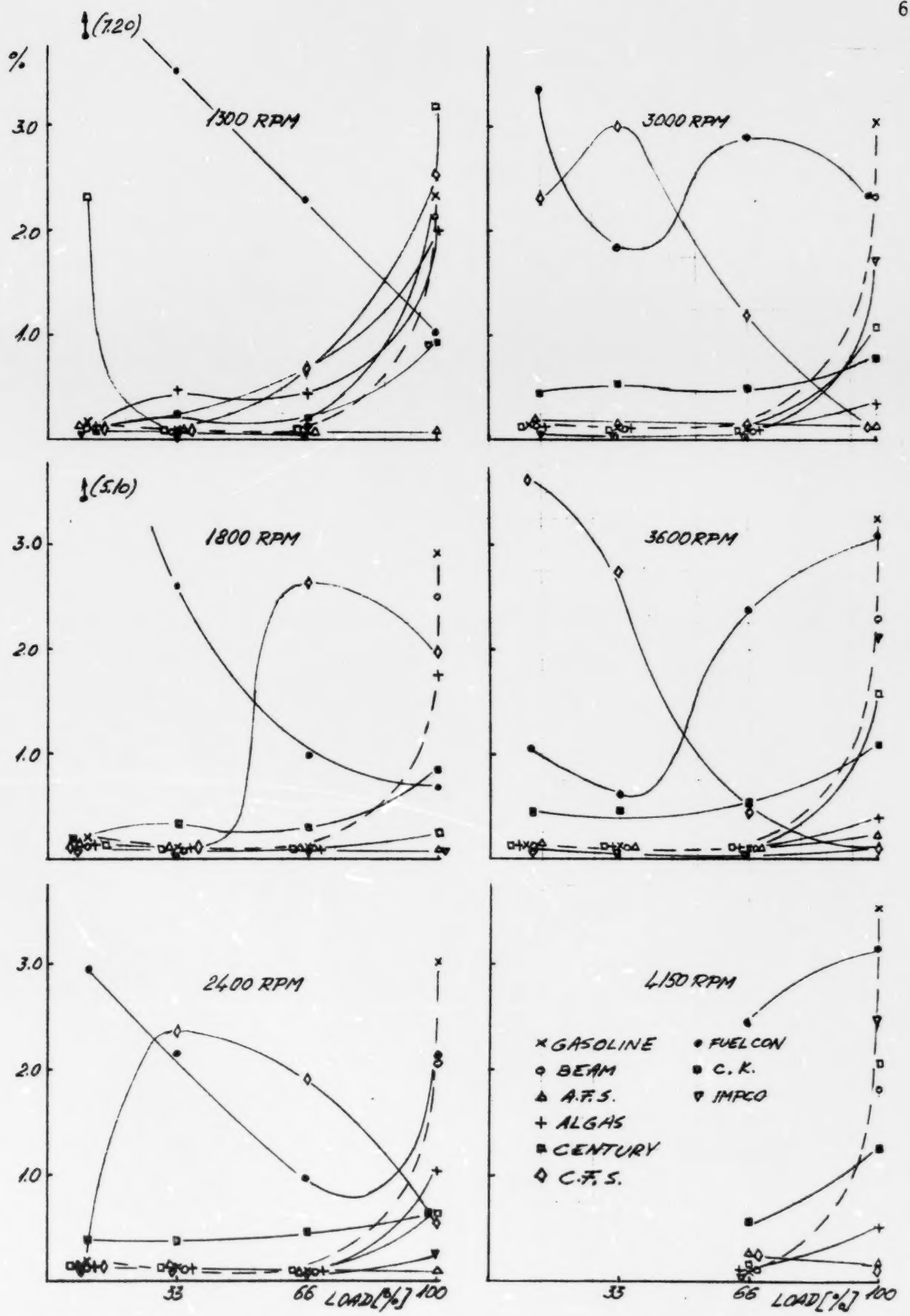


Figure 6-20: CO - emission at different loads and speeds- before catalytic converter (gasoline with emission controls, propane without)

For the better designed propane carburetion systems the level of this emission is lower than for gasoline at high loads, and at low loads becomes insignificant. For the systems less developed, the CO level is very high, sometimes increasing at low loads. As for HC, the concentration of CO increases at richer mixtures.

CO_2 emission is presented in Table 6-26. This emission presents a maximum in the stoichiometric region.

O_2 emission is given in Table 6-27 and Figure 6-21 and is an important indicator of the quality of the carburetion systems design. For the gasoline carburetor the level of O_2 increases with a regular shape from full load to partial loads at all speeds, up to a value of 3-4%. The propane systems have less uniform shapes, but still the best developed have the higher excess of oxygen. The concentration increases for leaner mixtures.

The NO emission is presented in Table 6-28 and Figure 6-22. The levels of this emission are generally higher than for gasoline. The correlation between the concentration of NO and air-fuel ratio is given in Table 6-29 and Figure 6-23. The average value presents a maximum at about A/F=17.2. To obtain levels of NO emission comparable with gasoline, the propane carburetion system has to run at A/F=20, and that is too lean (about 1.27 stoichiometric). A compromise is desirable around A/F=19 (about 1.20 stoichiometric), where the fuel economy is

Table 6-26: CO_2 Emission
%, average values
(before catalytic converter; gasoline with emission controls, propane without)

LOAD (%)	SYSTEM	Engine speed (RPM)						
		600	1300	1800	2400	3000	3500	4150
100	GASOL.		13.12	12.57	12.80	12.72	12.67	12.75
	BEAM		12.68	12.25	12.63	11.88	11.65	11.55
	A.F.S.		12.50	13.50	13.75	13.68	13.38	13.50
	ALGAS		11.88	12.00	12.50	12.90	13.00	12.78
	CENTURY		11.25	13.00	12.75	12.50	12.25	11.88
	C.F.S.		11.85	11.88	12.80	12.68	12.68	12.75
	FUELCON		12.63	13.00	12.00	11.75	11.08	11.00
	C.K.		12.38	12.25	12.63	12.38	12.50	12.38
	IMPCO		12.93	12.70	13.38	12.58	12.38	12.08
66	GASOL.		13.58	13.02	13.17	12.75	12.82	12.92
	BEAM		12.63	12.63	12.38	11.60	11.10	11.25
	A.F.S.		13.13	13.40	13.25	13.33	13.03	13.25
	ALGAS		11.80	11.88	11.88	11.90	11.78	12.03
	CENTURY		10.75	10.50	10.38	11.13	11.88	12.08
	C.F.S.		12.58	11.50	11.95	12.50	12.88	12.98
	FUELCON		11.75	12.73	12.63	11.25	11.53	11.35
	C.K.		12.75	12.63	12.88	12.70	13.00	12.75
	IMPCO		11.63	11.48	11.08	11.25	11.88	12.05
33	GASOL.		12.45	12.55	12.85	12.52	12.72	-
	BEAM		11.33	11.33	11.38	11.00	10.90	-
	A.F.S.		12.88	13.13	13.28	13.25	12.75	-
	ALGAS		11.38	11.53	11.88	12.13	11.88	-
	CENTURY		10.50	10.13	9.25	9.30	10.00	-
	C.F.S.		10.35	12.25	11.63	11.23	11.25	-
	FUELCON		10.75	11.58	11.85	12.05	12.55	-
	C.K.		12.50	12.50	12.88	12.88	13.00	-
	IMPCO		11.63	11.30	11.70	10.95	10.70	-
~10	GASOL.	10.67	12.47	12.20	12.55	12.50	12.75	-
	BEAM	12.65	10.30	10.73	11.08	10.90	10.78	-
	A.F.S.	13.13	12.13	12.75	13.00	13.00	13.00	-
	ALGAS	11.88	11.43	11.25	11.50	11.88	11.90	-
	CENTURY	12.50	11.75	12.53	9.60	9.45	9.20	-
	C.F.S.	10.75	10.50	9.90	11.50	11.68	10.75	-
	FUELCON	12.13	8.10	9.60	11.15	10.95	12.35	-
	C.K.	11.95	12.50	12.50	12.75	12.88	13.00	-
	IMPCO	12.05	12.55	12.15	11.53	11.55	10.80	-

Table 6-27: O_2 Emission
%, average values
(before catalytic converter; gasoline with emission controls, propane without)

LOAD (%)	SYSTEM	Engine speed (RPM)						
		600	1300	1800	2400	3000	3600	4150
100	GASOL.		0.95	0.60	0.42	0.37	0.28	0.19
	BEAM		0.28	0.26	0.29	0.21	0.19	0.24
	A.F.S.		1.95	0.80	0.68	0.53	0.75	0.63
	ALGAS		0.40	0.30	0.23	0.45	0.43	0.33
	CENTURY		0.60	0.45	0.40	0.35	0.35	0.15
	C.F.S.		0.87	0.25	0.46	0.94	1.05	0.87
	FUELCON		0.55	0.28	0.17	0.19	0.14	0.12
	C.K.		0.78	0.45	0.50	0.56	0.59	0.40
	IMPCO		0.72	1.39	0.63	0.24	0.20	0.20
66	GASOL.		2.08	2.25	2.33	2.47	2.65	2.63
	BEAM		1.88	2.03	2.23	2.50	2.91	2.50
	A.F.S.		1.28	0.95	1.10	0.80	1.05	0.60
	ALGAS		2.08	1.78	1.70	1.73	2.13	1.83
	CENTURY		4.30	4.60	4.76	3.13	2.05	1.58
	C.F.S.		1.31	0.46	0.29	0.25	0.30	0.49
	FUELCON		0.57	0.39	0.29	0.20	0.19	0.17
	C.K.		0.75	0.50	0.40	0.39	0.51	0.45
	IMPCO		3.15	3.08	4.05	3.33	2.53	2.20
33	GASOL.		3.45	3.07	2.85	3.03	2.82	-
	BEAM		4.00	3.88	3.50	3.45	3.14	-
	A.F.S.		1.58	1.33	1.03	0.98	1.28	-
	ALGAS		2.74	2.33	1.95	1.70	1.85	-
	CENTURY		4.48	5.18	6.55	5.95	4.90	-
	C.F.S.		5.10	1.73	0.58	0.32	0.27	-
	FUELCON		0.58	0.50	0.43	0.25	0.21	-
	C.K.		0.93	0.80	0.60	0.43	0.47	-
	IMPCO		2.93	3.18	2.90	3.98	4.08	-
~10	GASOL.	5.63	3.38	3.55	3.03	3.10	2.85	-
	BEAM	1.10	4.88	4.65	4.08	3.83	3.55	-
	A.F.S.	0.65	2.37	1.95	1.63	1.33	1.20	-
	ALGAS	0.75	2.78	2.85	2.55	2.18	1.80	-
	CENTURY	1.03	0.58	1.60	5.80	5.55	6.10	-
	C.F.S.	1.30	4.10	5.33	2.75	0.62	0.34	-
	FUELCON	1.90	0.88	0.53	0.43	0.33	0.32	-
	C.K.	1.83	1.25	1.03	0.78	0.55	0.45	-
	IMPCO	0.88	1.80	2.10	3.13	3.15	4.03	-

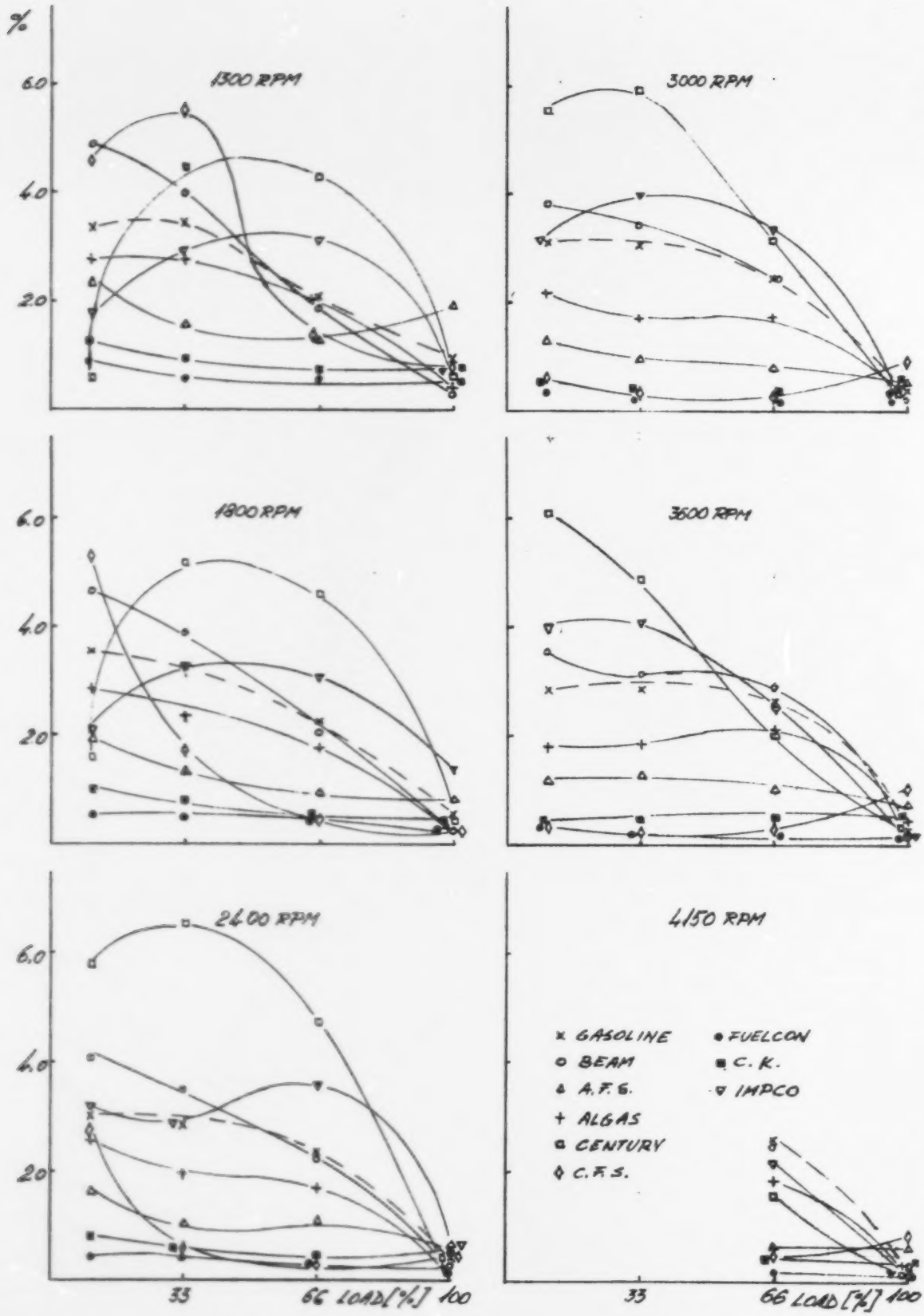


Figure 6-21: O_2 - emission at different loads and speeds - before catalytic converter (gasoline with emission controls, propane without)

Table 6-28: NO Emission
PPM, average values
(before catalytic converter; gasoline with emission controls, propane without)

LOAD (%)	SYSTEM	Engine speed (RPM)						
		600	1300	1800	2400	3000	3600	4150
100	GASOL.		1627	1523	1373	1433	1547	1487
	BEAM		1805	1755	2155	2125	2310	2625
	A.F.S.		3600	3450	3475	3450	3275	3125
	ALGAS		1575	1950	2625	3300	3350	3000
	CENTURY		790	2900	2755	2540	2140	1775
	C.F.S.		1170	1590	3065	3150	3000	2775
	FUELCON		2260	2575	1660	1610	1250	1130
	C.K.		2375	2360	2600	2335	2210	1825
	IMPCO		1950	2200	2050	1525	1285	1075
66	GASOL.		1000	1120	1180	1410	1513	1500
	BEAM		4100	4375	4550	4550	4625	4450
	A.F.S.		4375	4400	4700	4675	5050	4550
	ALGAS		4450	4600	4965	5075	4925	5000
	CENTURY		1585	835	1000	3450	4525	4725
	C.F.S.		3225	1600	2375	3225	4150	4400
	FUELCON		1520	3075	3225	1675	2260	2525
	C.K.		3550	3600	3650	3925	3975	3950
	IMPCO		2575	2650	500	1775	3000	3300
33	GASOL.		287	365	580	883	1010	-
	BEAM		2125	2400	2900	3325	3450	-
	A.F.S.		3350	3650	3800	4100	4300	-
	ALGAS		3100	3550	3950	3975	4200	-
	CENTURY		1550	785	415	565	1300	-
	C.F.S.		1690	3425	1830	1650	1740	-
	FUELCON		785	1535	1640	2375	3125	-
	C.K.		2875	3050	3100	3125	3200	-
	IMPCO		1925	1690	1875	1310	1230	-
~10	GASOL.	16	57	88	161	325	570	-
	BEAM	30	15	288	1000	1750	2288	-
	A.F.S.	29	67	1025	2100	2825	3450	-
	ALGAS	27	64	745	1650	2675	3225	-
	CENTURY	26	90	895	270	293	465	-
	C.F.S.	26	26	203	1540	1600	1150	-
	FUELCON	16	43	240	1090	1125	2260	-
	C.K.	6	115	1050	1785	2250	2460	-
	IMPCO	31	91	363	690	1095	890	-

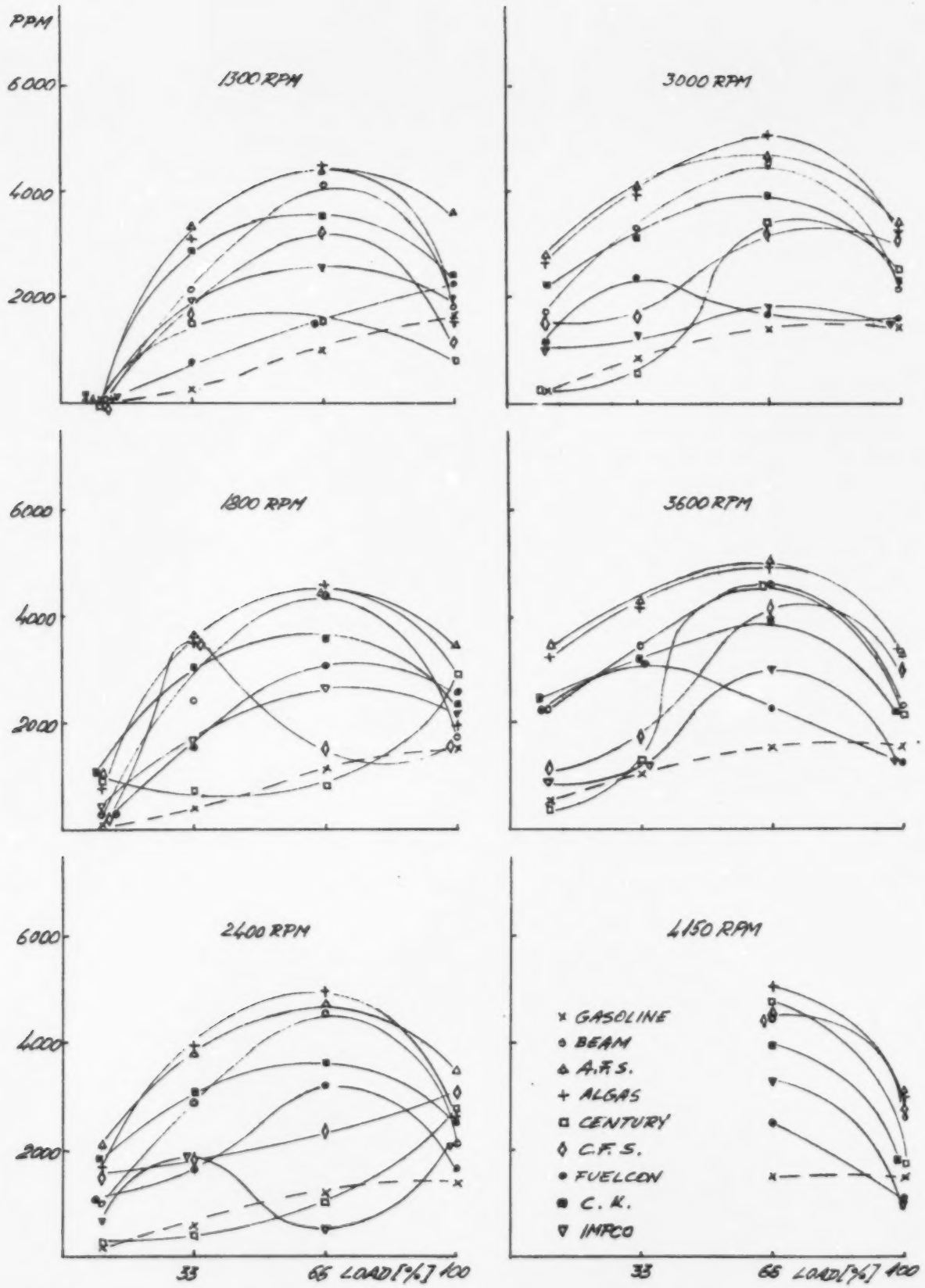


Figure 6-22: NO - emission at different loads and speeds- before catalytic converter(gasoline with emission controls, propane without)

Table 6-29: Dependence of NO emission (PPM) of air-fuel ratio (100, 66 and 33% of full load)

A/F	14	15	16	17	18	19	20	21
Average	1706	3000	3776	3948	2825	1199	1043	490
Standard deviation	461	654	729	994	1015	443	364	107
No. of points	32	36	26	18	13	7	2	2

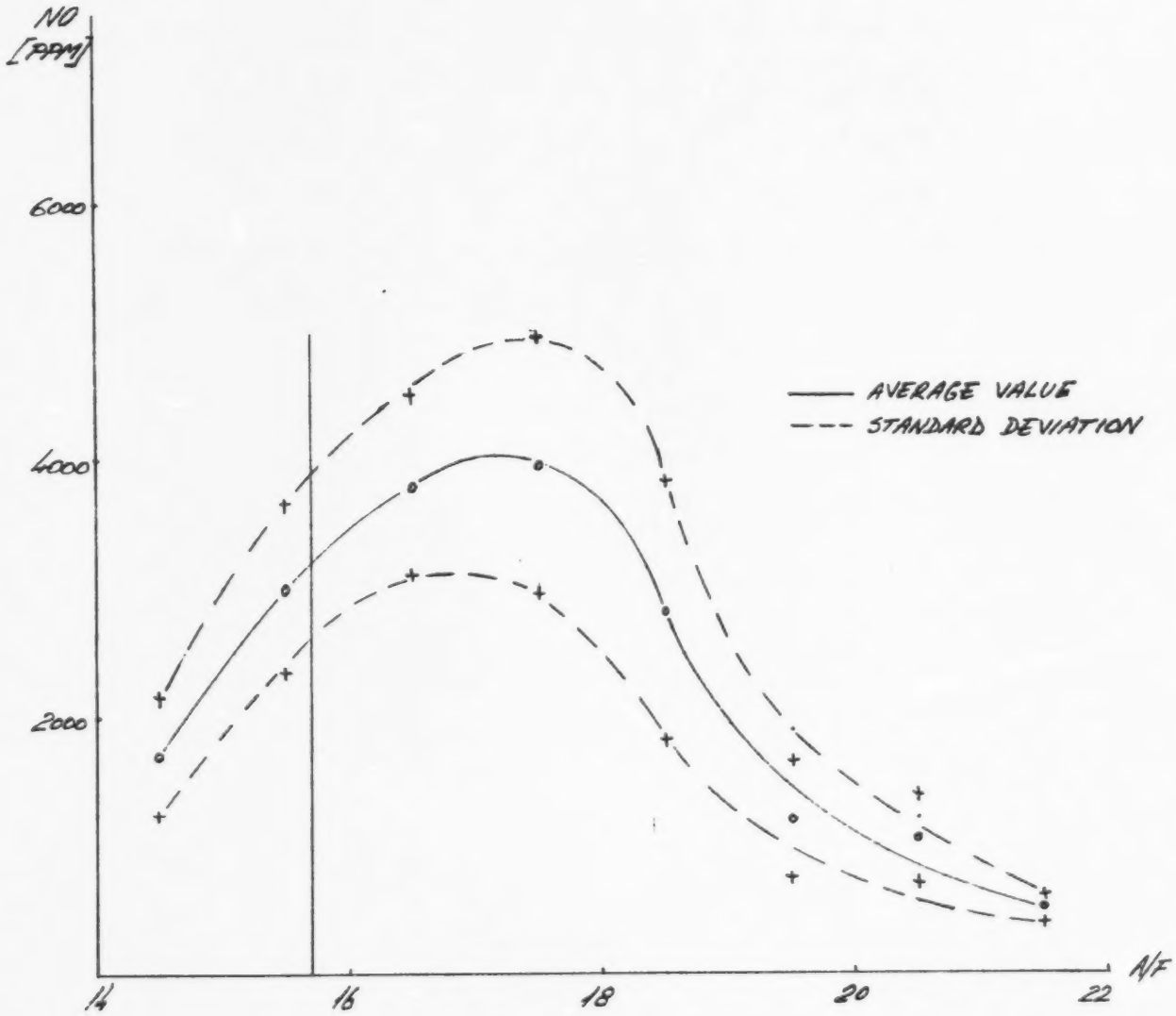


Figure 6-23: Correlation between NO-emission and air-fuel ratio for 100 - 66 - 33% of full load (propane systems)

also good, and backfire will not occur.

The main factor determining the fuel economy and emissions level - air-fuel ratio - is presented in Tables 6-30, 6-31 and Figure 6-24. The values are calculated from the emissions measured during the tests, with the method developed in Appendix 2. As for the oxygen content in emissions, which exercises a strong influence on the A/F curves shape, the difference between the design of gasoline and propane carburetors is evident. The value of A/F ratio for gasoline increases rapidly for partial loads and then is almost constant, at about 16.5 to 17.0 (1.13 to 1.16 stoichiometric). For the propane carburetion systems the curves are very different in shape and values.

The time history of the engine is given in Figure 6-25. At the end of the test program the mechanical condition can be described as follows:

- the results of the compression tests are presented in Table 6-31.

Table 6-31: Compression Test (psi)

Tests	Cylinder no.					
	1	2	3	4	5	6
After run-in	140	137	145	135	137	135
End of program	162	165	145	155	145	155

Table 6-30: A/F Ratio
(stoichiometric A/F for propane ≈ 15.69, for gasoline ≈ 14.59)
average values

LOAD	SYSTEM	Engine speed (RPM)						
		600	1300*	1800	2400	3000	3600	4150*
100	GASOL.		14.14	13.66	13.56	13.53	13.41	13.27
	BEAM		14.69	14.54	14.83	14.64	14.66	14.91
	A.F.S.		17.02	16.13	16.07	15.99	16.13	16.07
	ALGAS		14.75	14.84	15.22	15.82	15.81	15.69
	CENTURY		14.34	15.78	15.58	15.34	15.11	14.75
	C.F.S.		14.86	14.72	15.67	16.34	16.45	16.30
	FUELCON		15.35	15.38	14.65	14.58	14.19	14.18
	C.K.		15.60	15.46	15.67	15.67	15.56	15.35
	IMPCO		15.59	16.64	15.97	14.99	14.79	14.64
66	GASOL.		15.99	16.17	16.25	16.42	16.56	16.55
	BEAM		16.86	17.06	17.33	17.67	18.12	18.46
	A.F.S.		16.42	16.23	16.44	16.21	16.45	16.03
	ALGAS		16.93	17.00	17.01	17.05	17.40	17.15
	CENTURY		19.10	19.55	19.80	18.26	17.31	16.92
	C.F.S.		16.07	14.53	14.82	15.20	15.67	15.96
	FUELCON		14.74	15.29	15.28	14.29	14.56	14.53
	C.K.		15.97	15.78	15.67	15.69	15.74	15.74
	IMPCO		18.07	18.08	19.01	18.40	17.67	17.42
33	GASOL.		17.12	16.83	16.64	16.88	16.68	-
	BEAM		18.65	18.65	18.44	18.51	18.30	-
	A.F.S.		16.61	16.49	16.32	16.32	16.61	-
	ALGAS		17.44	17.42	17.15	16.95	17.13	-
	CENTURY		19.25	20.10	21.87	21.33	20.07	-
	C.F.S.		19.95	16.84	14.77	14.31	14.46	-
	FUELCON		14.14	14.55	14.75	14.84	15.47	-
	C.K.		16.05	15.98	15.85	15.66	15.74	-
	IMPCO		17.87	18.17	17.92	18.70	19.15	-
∿10	GASOL.	18.46	16.90	17.17	16.79	16.89	16.67	-
	BEAM	15.32	19.57	19.40	18.92	18.77	18.62	-
	A.F.S.	15.27	17.26	16.93	16.76	16.55	16.51	-
	ALGAS	14.71	17.68	17.82	17.60	17.31	17.05	-
	CENTURY	15.53	14.52	16.70	20.96	20.83	21.55	-
	C.F.S.	15.35	19.01	18.50	17.77	14.84	14.04	-
	FUELCON	16.39	12.46	13.33	14.34	14.13	15.31	-
	C.K.	16.62	15.21	16.23	15.96	15.78	15.77	-
	IMPCO	15.21	16.91	17.20	18.10	18.12	19.05	-

* extrapolated values

Table 6-31: A/F Equivalence Ratio $\left(\frac{A/F}{A/F_{stoich.}}\right)$

LOAD [%]	SYSTEM	Engine speed (RPM)						
		600	1300*	1800	2400	3000	3600	4150*
100	GASOLINE		0.969	0.936	0.929	0.927	0.919	0.910
	BEAM		0.936	0.927	0.945	0.933	0.934	0.950
	A.F.S.		1.085	1.028	1.024	1.019	1.028	1.024
	ALGAS		0.940	0.945	0.970	1.008	1.008	1.000
	CENTURY		0.914	1.006	0.993	0.978	0.963	0.940
	C.F.S.		0.947	0.938	0.999	1.041	1.048	1.040
	FUELCON		0.978	0.980	0.934	0.929	0.904	0.904
	C.K.		0.994	0.985	0.999	0.999	0.992	0.978
	IMPCO		0.994	1.061	1.018	0.955	0.943	0.933
66	GASOLINE		1.096	1.108	1.113	1.125	1.135	1.134
	BEAM		1.075	1.087	1.105	1.126	1.155	1.178
	A.F.S.		1.047	1.034	1.049	1.033	1.048	1.022
	ALGAS		1.079	1.084	1.084	1.087	1.109	1.093
	CENTURY		1.217	1.246	1.262	1.164	1.103	1.078
	C.F.S.		1.024	0.926	0.945	0.969	0.999	1.017
	FUELCON		0.940	0.975	0.974	0.911	0.928	0.926
	C.K.		1.018	1.006	0.999	1.000	1.003	1.003
	IMPCO		1.152	1.152	1.212	1.173	1.126	1.110
33	GASOLINE		1.173	1.154	1.141	1.157	1.143	-
	BEAM		1.189	1.189	1.175	1.180	1.166	-
	A.F.S.		1.059	1.051	1.040	1.040	1.059	-
	ALGAS		1.112	1.110	1.093	1.080	1.092	-
	CENTURY		1.227	1.281	1.394	1.360	1.279	-
	C.F.S.		1.272	1.073	0.941	0.912	0.922	-
	FUELCON		0.901	0.927	0.940	0.946	0.984	-
	C.K.		1.023	1.019	1.010	0.998	1.003	-
	IMPCO		1.139	1.158	1.142	1.192	1.221	-
~10	GASOLINE	1.265	1.158	1.177	1.151	1.158	1.143	-
	BEAM	0.976	1.247	1.237	1.206	1.196	1.187	-
	A.F.S.	0.973	1.100	1.079	1.068	1.055	1.052	-
	ALGAS	0.938	1.127	1.136	1.122	1.103	1.087	-
	CENTURY	0.990	0.925	1.064	1.336	1.328	1.374	-
	C.F.S.	0.978	1.212	1.179	1.133	0.946	0.895	-
	FUELCON	1.045	0.794	0.850	0.914	0.901	0.976	
	C.K.	1.059	0.969	1.034	1.017	1.006	1.005	-
	IMPCO	0.969	1.078	1.096	1.154	1.155	1.214	-

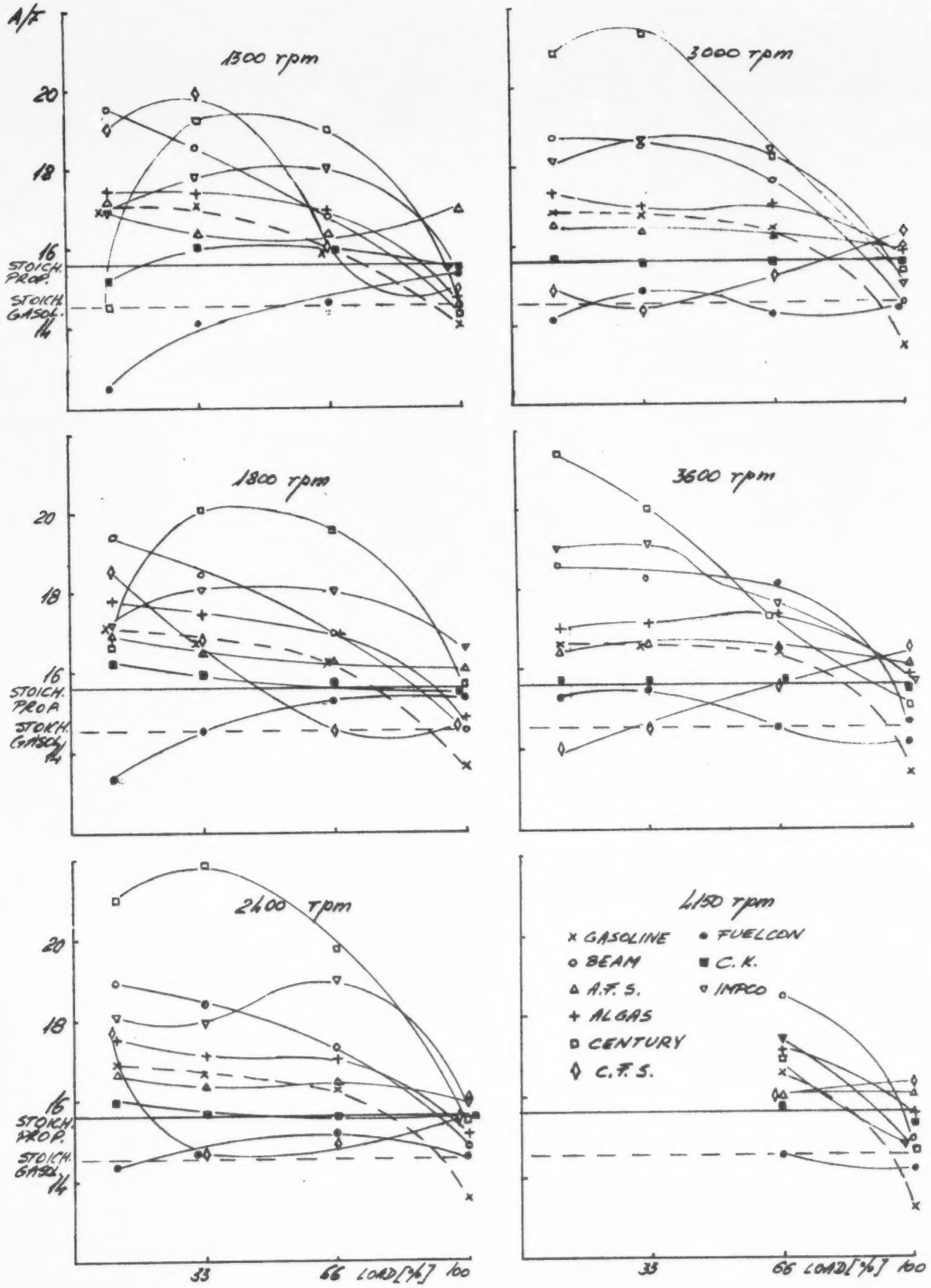


Figure 6-24 : Air-fuel ratio at different loads and speeds

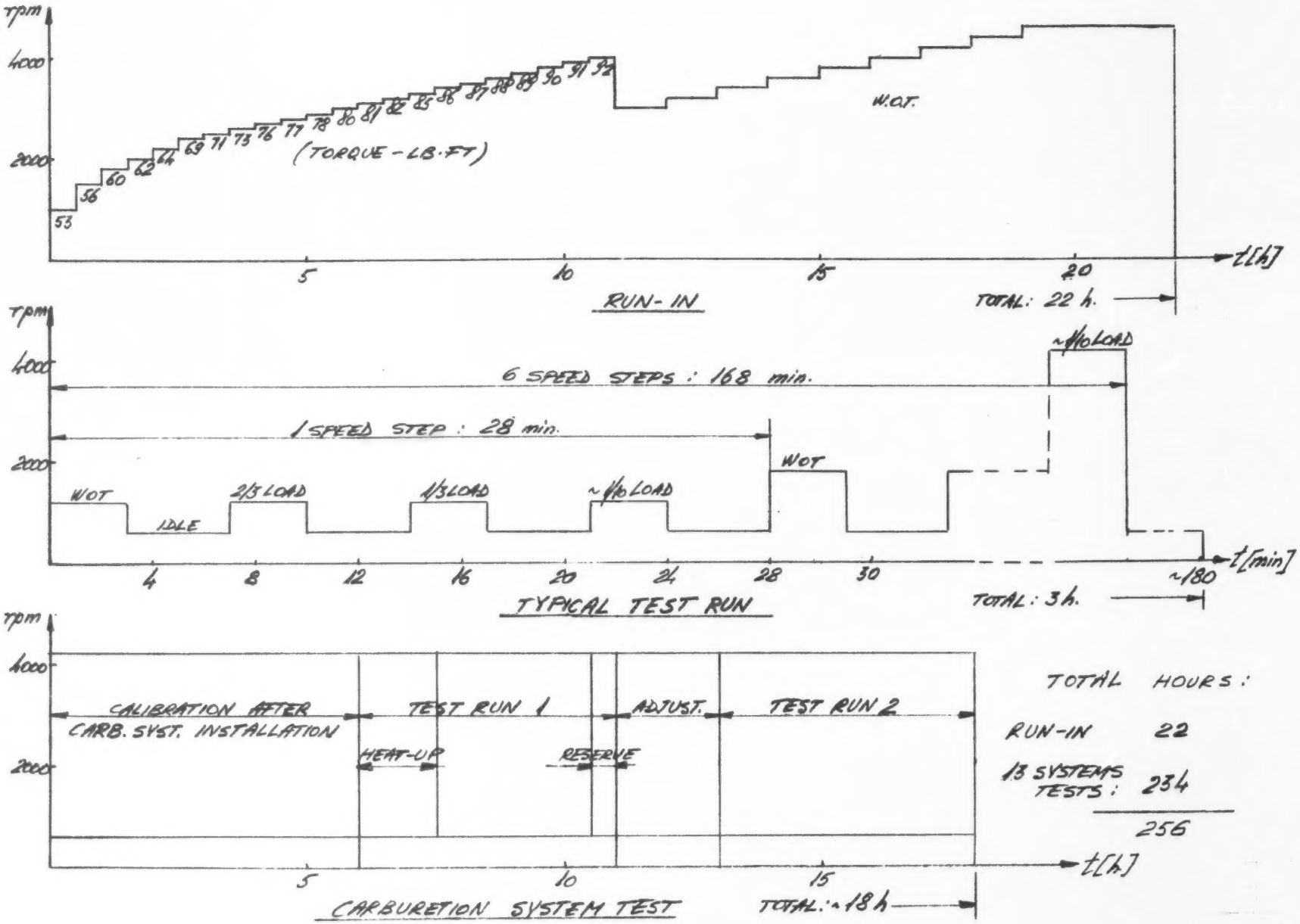


Figure 6-25: Time history of GM 229 CID V6 code K engine serial no. D9M 1810 4792428

- rings and valves are in good condition
- no increased noise or vibration
- plugs in very good condition, clean, gap unchanged
- the oil GULF SUPER PLUS 15 W-40 was analyzed by Gulf Research and Development Department and the results are presented in Table 6-32.

Table 6-32: Oil analysis comparative results

Characteristic	Test Method	Sample		
		Gasoline test 40 h.	Propane test 120 h.	Propane test 200 h.
CS at 40°C	D445	90.67	92.41	89.60
CS at 100°C	D445	12.11	12.46	11.78
Viscosity index	D2270	127	130	123
Tan		2.7	2.7	4.1
TBN		8.4	8.0	0.9
SO_4 ash		0.97	0.97	1.02
Insol.		0.08	0.04	0.14
Glycol		neg.	neg.	neg.
Water %		nil	nil	nil
Dilution%		0.4	0.4	0.0
Wear Metals-PPM				
Cu		8	4	25
Si		106	25	151
Al		4	1	21
Cr		0	0	5
Fe		55	30	205
Sn		3	0	24
Pb		18	8	0

- engine flushed with same oil after run-in
- oil changed after gasoline test

In the opinion of the Gulf laboratory the engine and the oil are in fair condition, oil requiring change. The Si level is high and the same happened in a fleet using propane on GM engines. GM Company is analyzing the problem. The level of Fe is normal after the length and severity of service.

7. OPTIMIZATION OF IMPCO CARBURETION SYSTEM ON GM V6 CODE K ENGINE

7.1 Procedure

Only the influence of timing and air-fuel ratio were analyzed in this report

7.1.1 Influence of timing at full throttle (see Figure 7-1)

- set ignition manually, isolating the vacuum advance and moving the body of the distributor until the desired timing angle is read
- stabilize on lowest desired speed with spark retarded from the best torque timing
- observe torque
- advance spark 2 degrees and observe torque, maintaining the speed constant
- repeat until a 2-degree advance shows no improvement in torque
- retard 1 degree, check that speed and torque are unchanged, and run at determined minimum for best torque (MBT) advance
- repeat in speed increments to maximum test speed

7.1.2 Influence of timing at partial loads (see Figure 7-2)

- set ignition manually
- stabilize at lowest desired speed, 2/3 or 1/3 of the MBT torque and with the spark retarded from the point of minimum specific fuel consumption
- run the test and compute brake specific fuel consumption

Figure 7-1: Principle of timing optimization at WOT, for MBT (minimum for best torque)

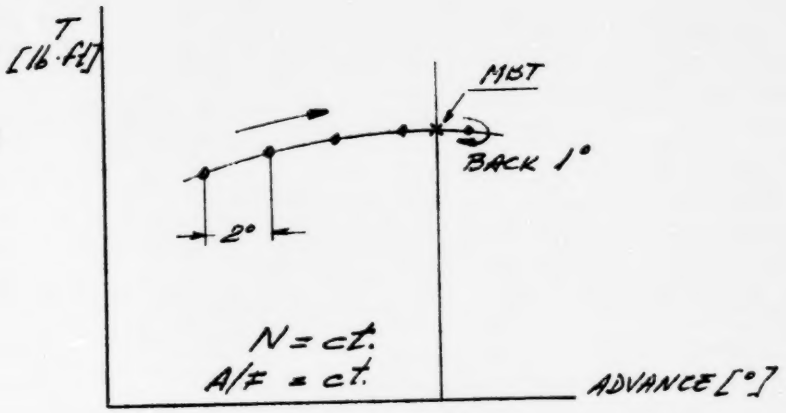


Figure 7-2: Principle of timing optimization at partial loads for minimum BSFC

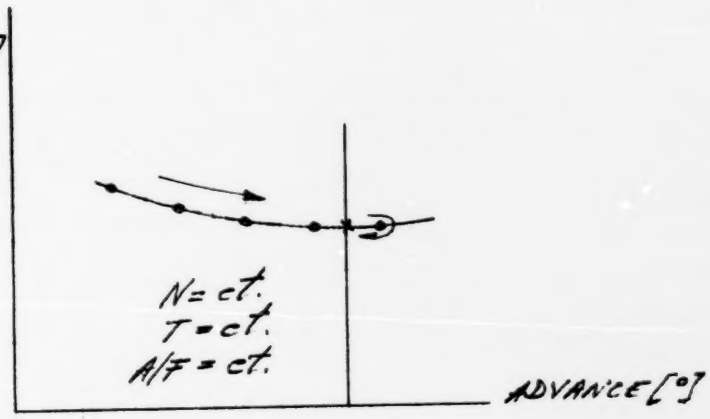
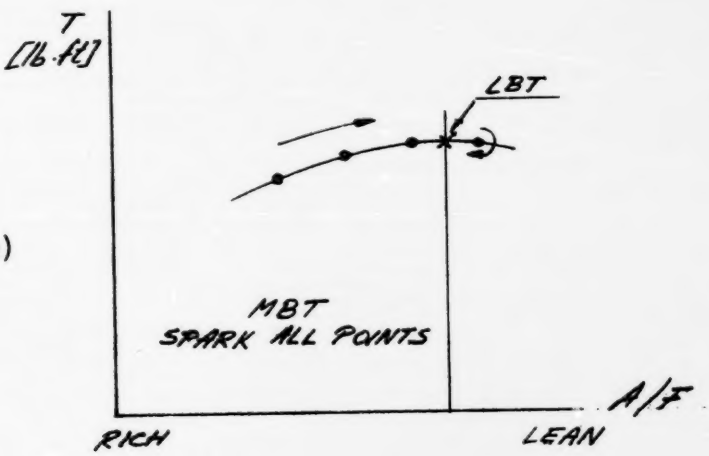


Figure 7-3: Principle of air-fuel ratio optimization at WOT, for LBT (leanest for best torque)



- advance spark 2 to 4 degrees, run the test maintaining speed and torque constant and compute BSFC
- repeat until BSFC reach a minimum and starts to rise again
- retard to the point of minimum BSFC and run the test to check that the value is unchanged
- repeat in speed increments to maximum test speed

7.1.3 Influence of air-fuel ratio at full throttle (see Figure 7-3)

- adjust carburetion system , controlling the opening of power valve between the vaporizer/regulator and the carburetor
- set ignition manually
- stabilize at lowest desired speed with the carburetion system richer than leanest for best torque (LBT) and spark retarded from MBT setting
- observe torque
- proceed as for MBT determination (7.1.1)
- observe torque at MBT
- lean air-fuel mixture
- readjust spark to MBT
- observe torque
- lean air-fuel mixture and readjust spark to MBT until torque falls below previous value at MBT
- adjust mixture richer, midway between last two settings
- adjust spark to MBT, check that torque is equal to previous maximum value and run the test
- repeat in speed increments to maximum test speed

7.2 Optimization Results

7.2.1 Timing at Full Throttle

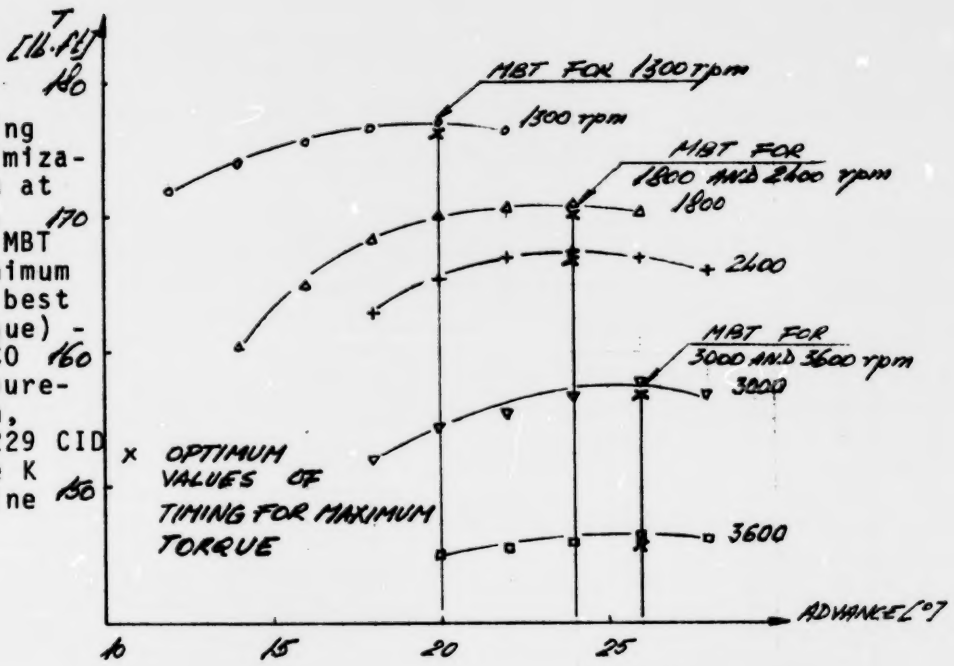
The results of the optimization test are presented in Table 7-1 and Figure 7-4.

Table 7-1: Influence of timing at full throttle

Speed (rpm)	Parameter	Test No. 1	2	3	4	5	6	7
1300 intended	Angle	12	14	16	18	20	22	-
	Actual speed	1321	1320	1360	1350	1360	1355	-
	Torque	171.9	174.0	175.8	176.8	177.0*	176.5	-
1800	Angle	14	16	18	20	22	24	26
	Torque	160.5	165.3	168.5	170.2	170.6	170.8*	170.4
2400	Angle	18	20	22	24*	26	28	-
	Torque	163.0	165.5	167.0	167.5	167.0	166.0	-
3000	Angle	18	20	22	24	26*	28	-
	Torque	152.0	154.5	155.7	157.0	158.0	157.00	-
3600	Angle	20	22	24	26*	28	-	-
	Torque	145.2	145.6	146.0	146.4	146.3	-	-

* Minimum for Best Torque (MBT) timing

In table 7-2 the fuel economy and corrected power for MBT timing are compared with the values obtained for the IMPCO system during testing of the 8 carburetion systems, at the same A/F setting.



gure 7-4: Timing optimization at WOT, for MBT (minimum for best torque) - IMPCO carburetion, GM 229 CID code K engine

Figure 7-5: Timing optimization at partial loads, for minimum BSFC - IMPCO carburetion, GM 229 CID code K engine

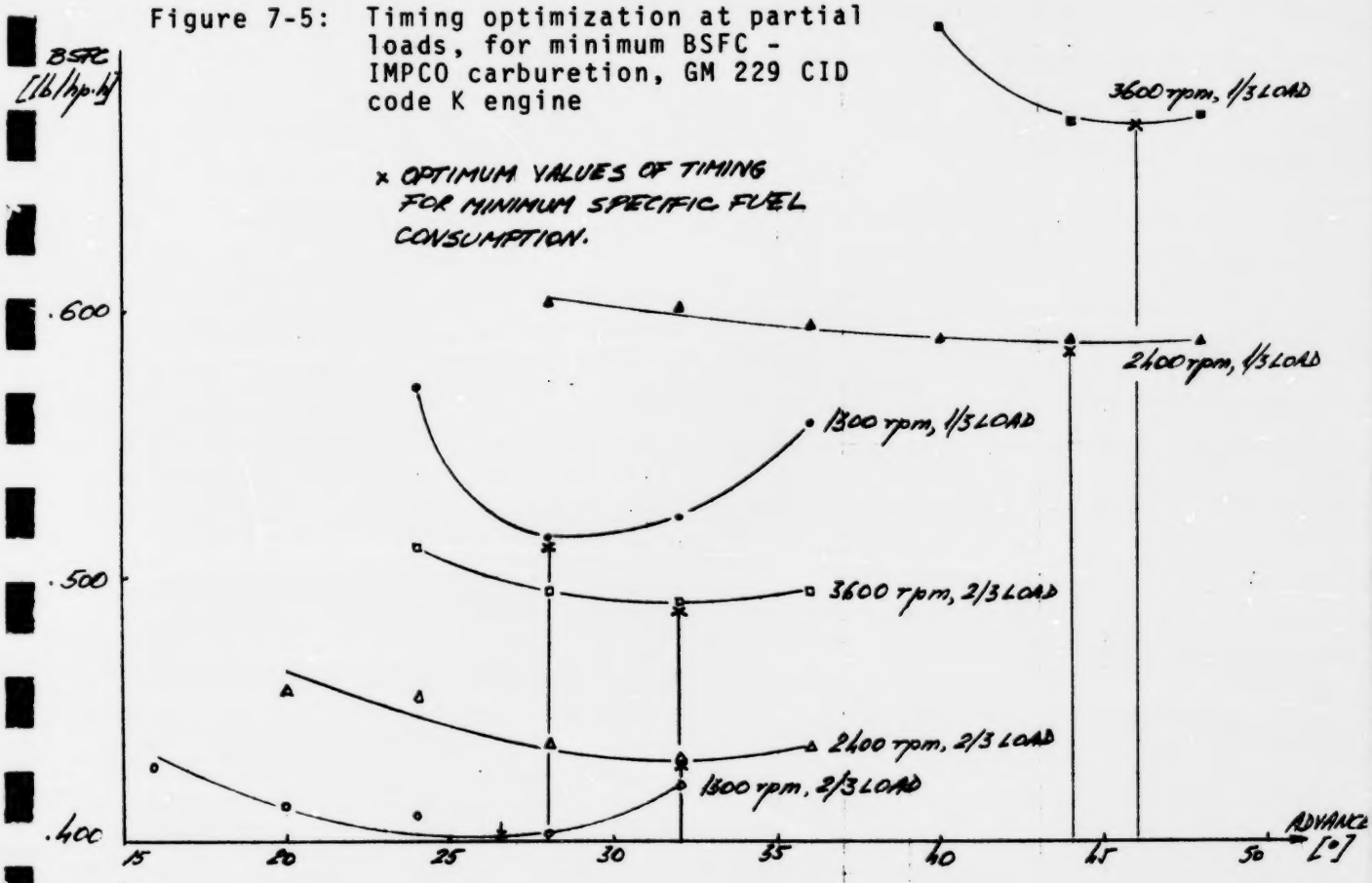


Table 7-2: Comparison of IMPCO performance during the test and after timing optimization (A/F constant)

Parameter	UM	Condition	Speed (rpm)				
			1300	1800	2400	3000	3600
Corrected power	hp	Test	42.90	57.41	75.16	88.57	98.62
		Timing Optimization	43.46	57.65	75.20	88.60	98.60
		Improvement after optim.%	+1.3	+0.42	0	0	0
Brake specific fuel consumption	$\frac{lb}{hp.h}$	Test	.420	.392	.414	.462	.483
		Timing Optimization	.390	.385	.417	.460	.486
		Improvement after optim.%	-7.1	-1.8	0	0	0

Except for the speeds of 1300 and 1800 rpm, where the improvement is due to the difference of timing between test and optimum, at higher speeds the timing was very near the optimum and consequently no room was available for improvement.

7.2.2 Timing at partial loads

The results of the optimization test for 2/3 and 1/3 of WOT torque are presented in Table 7-3 and Figure 7-5.

Table 7-3: Influence of timing at partial loads

Speed	Load	Parameter	Test no.					
			1	2	3	4	5	6
1300	2/3	Angle	16	20	24	28*	32	
		Actual torque	118.0	118.5	120.1	118.0	118.8	
		Vacuum	3.3	4.2	4.2	4.9	4.6	
		Fuel cons.[lb]	0.62	0.63	0.63	0.61	0.64	
		BFSC [lb/hp.h]	.429	.414	.410	.404	.421	
	1/3	Angle	24	28*	32	36		
		Actual torque	58.8	58.6	58.7	58.9		
		Vacuum	11.7	12.2	12.5	12.5		
		Fuel cons.[lb]	0.43	0.39	0.40	0.42		
		BFSC [lb/hp.h]	.572	.515	.523	.559		
2400	2/3	Angle	20	24	28	32*	36	
		Actual torque	110.0	110.5	110.5	111.0	111.6	
		Vacuum	2.3	2.5	2.8	3.2	3.2	
		Fuel cons.[lb]	1.17	1.17	1.12	1.11	1.13	
		BFSC [lb/hp.h]	.457	.455	.436	.431	.435	
	1/3	Angle	28	32	36	40	44*	48
		Actual torque	55.6	55.8	55.3	55.8	55.9	55.2
		Vacuum	11.4	11.4	11.8	11.7	11.7	11.7
		Fuel cons.[lb]	0.77	0.77	0.74	0.74	0.76	0.72
		BFSC [lb/hp.h]	.604	.602	.590	.579	.579	.579
3600	2/3	Angle	24	28	32*	36		
		Actual torque	97.8	97.5	97.0	96.5		
		Vacuum	4.5	4.5	4.8	4.5		
		Fuel cons.[lb]	1.74	1.68	1.67	1.66		
		BFSC [lb/hp.h]	.512	.495	.493	.495		
	1/3	Angle	40	44*	48	52		
		Actual torque	50.5	50.1	52.0	51.0		
		Vacuum	8.3	9.3	9.8	9.7		
		Fuel cons.[lb]	1.22	1.15	1.20	1.20		
		BFSC [lb/hp.h]	.708	.673	.674	.685		

* timing for best economy

The optimization results are presented together with the IMPCO comparative test in Table 7-4.

Table 7-4: Comparison of IMPCO brake specific fuel consumption at partial loads during the test and after timing optimization (A/F constant) (lb/hp.h)

Speed	1300		2400		3600	
Load / Condition	2/3	1/3	2/3	1/3	2/3	1/3
Test	.420	.531	.466	.576	.503	.698
Timing optimization	.404	.515	.431	.579	.493	.673
Improvement after optimiz. %	-3.8	-3.0	-7.5	0	-2.0	-3.6

7.2.3 Air-fuel ratio at full throttle

A broad spectrum of air-fuel ratios and its influence on performance and fuel economy is analyzed in Paragraph 6 (see Figures 6-3 and 6-6 to 6-9).

The power at WOT increases by 2.0 to 6.9% for each point of A/F going richer, depending on speed. The BSFC on energy base at WOT increases by approximately 5% for each point of A/F going richer. At partial loads the BSFC increases by approximately 2.7 to 4.1% for each point of A/F going

richer , depending on load and speed.

On the rich side of the stoichiometric mixture the collected data is scarce, so in this phase of the present work supplementary tests were conducted with richer mixtures on IMPCO carburetion system at WOT. The results are presented in Table 7-5.

The general tendency outlined before is confirmed by this last experiment.

No detonation was encountered during this series of tests.

Table 7-5: Comparison of IMPCO WOT performance during the test and with enriched mixture

Parameter		UM	Condition	Speed [rpm]		
				1300	2400	3600
A/F		-	Test	15.59	15.97	14.79
			Enriched	14.69	13.80	12.93
Emissions	HC	PPM	Test	143	37	55
			Enriched	200	150	240
	CO	%	Test	0.93	0.26	2.13
			Enriched	2.1	3.9	6.0
	CO_2	%	Test	12.93	13.38	12.38
			Enriched	11.50	10.50	10.25
	O_2	%	Test	0.72	0.63	0.20
			Enriched	0.35	0.20	0.10
	NO	PPM	Test	1950	2050	1285
			Enriched	1700	750	500
Power		hp	Test	42.90	75.16	98.62
			Enriched	43.72	77.53	100.90
			Change after Enrichment %	+1.9	+3.2	+2.3
BSFC		$\frac{lb}{hp.h}$	Test	.420	.414	.483
			Enriched	.430	.440	.510
			Change after Enrichment %	+2.4	+6.3	+5.6

8. CONCLUSIONS

8.1 Properly designed, installed and calibrated, the propane carburetion systems can deliver the same - or better - maximum power, energy efficiency and level of emissions than gasoline carburetors.

8.2 For the tested systems the corrected brake power at wide open throttle is 3.7 to 15.5% higher at 1300 rpm for propane, equals the power developed with gasoline at 2400 to 3000 rpm and is 3.7 to 15.5% lower at 4150 rpm.

8.3 For comparable A/F settings, the propane systems can develop 10% more power at 13000 rpm, 5% at 1800 rpm, and the same power as the gasoline system at higher speeds.

8.4 The energy efficiency of the eight propane systems tested varies on average between 4.5% higher and 7.5% lower compared to gasoline. For the best systems the efficiency varies between 9.2% higher and 1.3% lower.

8.5 For comparable A/F ratios, the propane systems can obtain on average 10-15% better energy efficiency at 1300 to 1800 rpm, 5-10% at 2400 rpm and 0-5% at higher speeds. Those in the conditions of the tests in this project -

steady state loads at stabilized work temperatures. For the conditions of real driving - cold starts, frequent changes of engine speed - supplementary energy efficiency gains can be expected.

8.6 In volume terms, the tested propane systems consumed between 13.2 and 78.7% more fuel, depending on load and speed. For the best systems, the maximum increase is 56.4%, but those values are unlikely to be encountered in practice, since they occur at highest engine speed. In practical terms (up to 3000 rpm), the maximum increase for the best systems is 43.8%.

8.7 Improvements of the propane carburetion systems and the differences between the conditons of those tests and the real driving can reduce the volume consumption increase with propane at 5-25%, depending on load and speed.

8.8 With this increase in volumetric consumption, the economical advantage of propane use as automotive fuel results mainly from the difference in price on an energy base. Being a by-product of oil industry, the price of propane for an equivalent energy content is considerably lower than for gasoline in many countries. In such conditions, the increase in volumetric consumption is exceeded by the price difference. Other

economical advantages result from the improvements in life of the engine, oil and spark plugs.

8.9 For the engine tested, the optimization of timing shows a range of 3 to 6% possible improvement in power and 2 to 8% in specific fuel consumption at full load, and 4 to 10% possible improvement in fuel economy at partial loads.

8.10 The exhaust temperatures with propane are higher than for gasoline at full load (up to 89°F) and lower at partial loads (down to 116°F). Retarded timing or air-fuel ratios near stoichiometric can increase the exhaust temperature with more than 100°F.

8.11 The emissions for the tested systems are generally higher than for gasoline, except CO emission for a few systems at full load (before catalytic converter/gasoline with emission controls, propane without).

8.12 The large spread of results for fuel economy and emissions is determined by the quality and the degree of engineering development of the propane carburetion systems. The use of the best systems or further development work for new systems will improve considerably the overall fuel economy and the level of emissions.

8.13 For best results, each particular model of engine has to be optimized for propane use, establishing by dynamometer testing the required air-fuel ratio and timing for the whole range of practical loads and speeds.

9. PROPOSAL FOR FUTURE WORK

During the work on this project a few ideas developed about the applied research necessary in the future to ensure the best results in propane carburetion application.

9.1 All the results of tests prove the major importance of the right air-fuel ratio and timing in the developed power and especially in the fuel economy and emissions obtained.

Testing is necessary in the area of propane carburetion systems functionment for a better understanding of the factors affecting the fuel metering at different loads and speeds. On this ground, development of improved metering systems is possible.

9.2 For the existing carburetion systems, the calibration performed at installation and periodically at tune-up times is also the main factor in obtaining the optimum results for fuel economy, emissions and power. The gasoline carburetion systems are very carefully developed and matched with a specific model of engine in the testing departments of the manufacturers. The variables left under the control of the mechanic at the installation and for periodic adjustments are kept at a minimum - now only the idle speed screw is accessible for setting and the idle mixture is sealed. The same for the

distributor - the curve is fixed and has to be only checked and the only possible adjustment is the static timing, to be done at the value recommended by the manufacturer. The type of spark plugs and the gap are factory-established. The value of cooling water thermostat is also fixed. All those basic variables are left to the discretion of the installer of the propane carburetion systems. He has to decide on the right manufacturer, model of equipment to match the engine to be converted, timing curve, spark plugs, cooling water temperature and settings for carburetor idle speed and mixture and power mixture. If the carburetor is provided with an economizer system, he has to concern himself with its calibration too, to obtain the best economy at partial loads. That is definitely not a task for a workshop. And because the propane carburetion systems are manufactured till now as "universal" systems adaptable to all the engines on the market, the Service Manuals offer only general guidance on how to install and calibrate the equipment, sometimes in incomplete, confusing or erroneous terms. Many companies don't offer the hardware necessary to adapt the carburetion system on a particular engine, so the installer has to take care of the design and construction of those adapters too, with all the possible consequences on the performance and safety of the installation.

A number of representative models of engines can be

optimized on the engine-dynamometer stand, establishing the necessary A/F and timing for best economy, performance and emissions.

9.3 Propane Carburetions Systems Calibration Manual can be written, based on the results of optimization and the experience accumulated with this type of carburetion. This Manual can contain lists of required equipment (chassis dynamometer, engine analyzer, emissions analyzers), operations sequences, check values, etc.

9.4 The research can be extended to cover the influence of higher compression ratios, design of camshafts, variable timing for knock control, closed loop carburetion systems (last two involving electronics and microcomputers use), to raise the level of propane carburetion systems to the level of modern gasoline carburetors.

APPENDIX 1

Calculations for Corrected Parameters

$$bp_t\ [hp] = \frac{T_t[lb.\ ft.] \cdot N_t[rpm]}{5252} \qquad (1)$$

bp_t = brake power; observed at test conditions

T = torque

N = speed

5252 = G, power constant

$$bmep_t\ \left[\frac{lb.}{in^2}\right] = \frac{396{,}000 \times 2}{229 \cdot N_t\ [rpm]}\ bp_t\ [hp] = 3458.515\ \frac{bp_t\ [hp]}{N_t\ [rpm]} \qquad (2)$$

bmep = brake mean effective pressure

396,000 = E, units of work conversion factor

2 = a, engine revolutions per cycle

229 = D, engine displacement [in^3]

$$fp_t\ [hp] = bp_t\ [hp]\ \left(\frac{100}{n[\%]} - 1\right) \qquad (3)$$

fp_t = friction power; observed

n = mechanical efficiency - see table 1 in SAE J816 b, at different bmep and rpm

$$F_t\ [lb./h] = W_t\ [lb.] \cdot \frac{60}{M[min]} \qquad (4)$$

F = fuel consumption

W = mass of fuel

M = time of fuel measurement

$$bsfc_t\ [lb/hp.h] = \frac{F_t[lb/h]}{bp_t\ [hp]} \qquad (5)$$

bsfc = brake specific fuel consumption

$$B_d[in\ Hg] = B[in\ Hg] - e[in\ Hg] \qquad (6)$$

B_d = barometric pressure - dry air conditions

e = water vapour pressure in atmosphere (see chart for wet-dry bulb temp.) 0.5.

$$C_s = \frac{29.00\ [in\ Hg]}{B_{dt}\ [in\ Hg]} \cdot \left(\frac{t_t\ [°F] + 460\ [°F]}{85\ [°F] + 460\ [°F]}\right)^{0.5} \qquad (7)$$

C_s = correction factor, for standard atmospheric conditions

29.00 = B_d*, standard ambient dry barametric pressure

B_{dt} = barametric pressure - observed

t_t = ambient temperature - observed

460 = A, correction for absolute temperature

85 = t*, standard ambient temperature

$$bp_c\ [hp] = (bp_t\ [hp] + fp_t\ [hp])\ \ C_s - fp_t\ [hp] \qquad (8)$$

C = corrected to standard conditions

$$T_c = \frac{5252}{N_t\ [rpm]} \cdot bp_c\ [hp] \qquad (9)$$

$$bmep_c = \frac{396{,}000 \times 2}{229.N_t\ [rpm]} \cdot bp_c\ [hp] = 3458.5\ \frac{bp_c\ [hp]}{N_t\ [rpm]} \qquad (10)$$

The relations (8) - (10) for a range of 28 ÷ 30 in Hg barometric pressure and 60 ÷ 110°F air inlet temperature.

When $bmep_t$ is in kPa:

$$n = \frac{100}{1 + \frac{6.89x - y \cdot bmep_t}{bmep_t}}$$

In both equations:

$$x = 16.3761 + 2.28629\left(\frac{N}{1000}\right) + 0.297053\left(\frac{N}{1000}\right)^2$$

$$y = \frac{1}{100}\left[5.44659 - 0.02495\left(\frac{N}{1000}\right) - 0.174376\left(\frac{N}{1000}\right)^2\right]$$

4.5.2.3 *Correction Calculation*—In the case of the spark ignition engines, in which the air-fuel ratio characteristically remains constant, this type of correction is directly applicable under all conditions

$$bp_c = (ip_t \cdot C_g) - fp_t$$
$$bp_c = (bp_t + fp_t) \cdot C_g - fp_t$$

Corrected brake torque, $T_c = \frac{G}{N} \cdot bp_c$

Corrected brake mean effective pressure, $bmep_c = \frac{\Gamma \cdot a}{D \cdot N} \cdot bp_c$

Fuel consumption—Because the exact manner in which atmospheric conditions affect fuel consumption is not known, a correction is not applied, and both fuel consumption and specific fuel consumption are reported as observed.

TABLE 1—MECHANICAL EFFICIENCY OF SPARK IGNITION ENGINES, %

	bmep, kPa																				
	138	152	165	179	193	207	221	234	248	262	276	290	303	317	331	345	358	372	386	400	414
	bmep, lb/in²																				
rpm	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60
800	53.6	56.1	58.4	60.4	62.4	64.1	65.7	67.2	68.6	69.9	71.1	72.2	73.3	74.3	75.2	76.1	76.9	77.7	78.4	79.1	79.8
1000	52.8	55.3	57.6	59.6	61.6	63.3	64.9	66.4	67.8	69.1	70.3	71.5	72.5	73.5	74.5	75.4	76.2	77.0	77.8	78.5	79.1
1200	51.9	54.4	56.7	58.8	60.7	62.5	64.1	65.6	67.1	68.4	69.6	70.7	71.8	72.8	73.8	74.7	75.5	76.3	77.1	77.8	78.5
1400	51.1	53.6	55.9	58.0	59.9	61.7	63.3	64.8	66.3	67.6	68.8	70.0	71.0	72.1	73.0	73.9	74.8	75.6	76.4	77.1	77.8
1600	50.2	52.8	55.0	57.1	59.1	60.8	62.5	64.0	65.4	66.8	68.0	69.2	70.3	71.3	72.3	73.2	74.1	74.9	75.7	76.4	77.1
1800	49.4	51.9	54.2	56.3	58.2	60.0	61.6	63.2	64.6	66.0	67.2	68.4	69.5	70.5	71.5	72.4	73.3	74.1	74.9	75.7	76.4
2000	48.5	51.0	53.3	55.4	57.4	59.1	60.8	62.3	63.8	65.1	66.4	67.6	68.7	69.7	70.7	71.6	72.5	73.4	74.2	74.9	75.6
2200	47.7	50.2	52.5	54.6	56.5	58.3	59.9	61.5	62.9	64.3	65.5	66.7	67.9	68.9	69.9	70.9	71.7	72.6	73.4	74.2	74.9
2400	46.8	49.3	51.6	53.7	55.6	57.4	59.1	60.6	62.1	63.4	64.7	65.9	67.0	68.1	69.1	70.0	70.9	71.8	72.6	73.4	74.1
2600	46.0	48.5	50.7	52.8	54.7	56.5	58.2	59.8	61.2	62.6	63.8	65.1	66.2	67.3	68.3	69.2	70.1	71.0	71.8	72.6	73.3
2800	45.1	47.6	49.9	51.9	53.9	55.7	57.3	58.9	60.3	61.7	63.0	64.2	65.3	66.4	67.4	68.4	69.3	70.2	71.0	71.8	72.6
3000	44.3	46.7	49.0	51.1	53.0	54.8	56.4	58.0	59.5	60.8	62.1	63.3	64.5	65.6	66.6	67.6	68.5	69.4	70.2	71.0	71.7
3200	43.5	45.9	48.1	50.2	52.1	53.9	55.6	57.1	58.6	60.0	61.3	62.5	63.6	64.7	65.7	66.7	67.6	68.5	69.4	70.2	70.9
3400	42.6	45.0	47.3	49.3	51.2	53.0	54.7	56.2	57.7	59.1	60.4	61.6	62.8	63.8	64.9	65.9	66.8	67.7	68.5	69.3	70.1
3600	41.8	44.2	46.4	48.5	50.4	52.1	53.8	55.4	56.8	58.2	59.5	60.7	61.9	63.0	64.0	65.0	66.0	66.8	67.7	68.5	69.3
3800	41.0	43.4	45.6	47.6	49.5	51.3	52.9	54.5	56.0	57.3	58.6	59.9	61.0	62.1	63.2	64.2	65.1	66.0	66.9	67.7	68.5
4000	40.2	42.5	44.7	46.8	48.6	50.4	52.1	53.6	55.1	56.5	57.8	59.0	60.2	61.3	62.3	63.3	64.2	65.1	66.0	66.8	67.6
4200	39.4	41.7	43.9	45.9	47.8	49.6	51.2	52.8	54.2	55.6	56.9	58.1	59.3	60.4	61.4	62.4	63.4	64.3	65.2	66.0	66.8
4400	38.6	40.9	43.1	45.1	47.0	48.7	50.3	51.9	53.3	54.7	56.0	57.2	58.4	59.5	60.6	61.6	62.5	63.4	64.3	65.1	65.9
4600	37.8	40.1	42.3	44.3	46.1	47.9	49.5	51.0	52.5	53.9	55.2	56.4	57.5	58.7	59.7	60.7	61.7	62.6	63.4	64.3	65.1
4800	37.1	39.4	41.5	43.4	45.3	47.0	48.7	50.2	51.6	53.0	54.3	55.5	56.7	57.8	58.8	59.9	60.8	61.7	62.6	63.4	64.2
5000	36.3	38.6	40.7	42.6	44.5	46.2	47.8	49.3	50.8	52.1	53.4	54.7	55.8	56.9	58.0	59.0	60.0	60.9	61.7	62.6	63.4
5200	35.6	37.8	39.9	41.8	43.7	45.4	47.0	48.5	49.9	51.3	52.6	53.8	55.0	56.1	57.1	58.1	59.1	60.0	60.9	61.7	62.5
5400	34.9	37.1	39.1	41.1	42.9	44.6	46.2	47.7	49.1	50.5	51.8	53.0	54.1	55.2	56.3	57.3	58.3	59.2	60.0	60.9	61.7
5600	34.2	36.3	38.4	40.3	42.1	43.8	45.4	46.9	48.3	49.6	50.9	52.1	53.3	54.4	55.4	56.4	57.4	58.3	59.2	60.0	60.9
5800	33.5	35.6	37.6	39.5	41.3	43.0	44.6	46.1	47.5	48.8	50.1	51.3	52.5	53.6	54.6	55.6	56.6	57.5	58.4	59.2	60.0
6000	32.8	34.9	36.9	38.8	40.5	42.2	43.8	45.3	46.7	48.0	49.3	50.5	51.6	52.7	53.8	54.8	55.7	56.7	57.5	58.4	59.2

	bmep, kPa																				
	414	427	441	455	469	483	496	510	524	538	552	565	579	593	607	620	634	648	662	676	689
	bmep, lb/in²																				
rpm	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
800	79.8	80.4	81.0	81.6	82.1	82.7	83.2	83.7	84.1	84.6	85.0	85.4	85.8	86.2	86.5	86.9	87.2	87.5	87.8	88.1	88.4
1000	79.1	79.8	80.4	81.0	81.5	82.1	82.6	83.1	83.5	84.0	84.4	84.8	85.2	85.6	86.0	86.3	86.7	87.0	87.3	87.6	87.9
1200	78.5	79.1	79.8	80.4	80.9	81.5	82.0	82.5	82.9	83.4	83.8	84.3	84.7	85.1	85.4	85.8	86.1	86.5	86.8	87.1	87.4
1400	77.8	78.5	79.1	79.7	80.3	80.8	81.3	81.9	82.3	82.8	83.2	83.7	84.1	84.5	84.9	85.2	85.6	85.9	86.3	86.6	86.9
1600	77.1	77.8	78.4	79.0	79.6	80.2	80.7	81.2	81.7	82.2	82.6	83.1	83.5	83.9	84.3	84.6	85.0	85.4	85.7	86.0	86.3
1800	76.4	77.1	77.7	78.3	78.9	79.5	80.0	80.5	81.0	81.5	82.0	82.4	82.8	83.3	83.7	84.0	84.4	84.8	85.1	85.4	85.8
2000	75.6	76.3	77.0	77.6	78.2	78.8	79.3	79.9	80.4	80.9	81.3	81.8	82.2	82.6	83.0	83.4	83.8	84.1	84.5	84.8	85.2
2200	74.9	75.6	76.3	76.9	77.5	78.1	78.6	79.2	79.7	80.2	80.6	81.1	81.5	82.0	82.4	82.8	83.1	83.5	83.9	84.2	84.5
2400	74.1	74.8	75.5	76.1	76.8	77.3	77.9	78.4	79.0	79.5	79.9	80.4	80.9	81.3	81.7	82.1	82.5	82.9	83.2	83.6	83.9
2600	73.3	74.1	74.7	75.4	76.0	76.6	77.2	77.7	78.2	78.7	79.2	79.7	80.2	80.6	81.0	81.4	81.8	82.2	82.5	82.9	83.2
2800	72.6	73.3	74.0	74.6	75.2	75.8	76.4	77.0	77.5	78.0	78.5	79.0	79.4	79.9	80.3	80.7	81.1	81.5	81.9	82.2	82.6
3000	71.7	72.5	73.2	73.8	74.5	75.1	75.7	76.2	76.8	77.3	77.8	78.3	78.7	79.2	79.6	80.0	80.4	80.8	81.2	81.5	81.9
3200	70.9	71.7	72.4	73.0	73.7	74.3	74.9	75.4	76.0	76.5	77.0	77.5	78.0	78.4	78.9	79.3	79.7	80.1	80.5	80.8	81.2
3400	70.1	70.8	71.6	72.2	72.9	73.5	74.1	74.7	75.2	75.7	76.3	76.8	77.2	77.7	78.1	78.6	79.0	79.4	79.8	80.1	80.5
3600	69.3	70.0	70.7	71.4	72.1	72.7	73.3	73.9	74.4	75.0	75.5	76.0	76.5	76.9	77.4	77.8	78.2	78.6	79.0	79.4	79.8
3800	68.5	69.2	69.9	70.6	71.3	71.9	72.5	73.1	73.6	74.2	74.7	75.2	75.7	76.2	76.6	77.1	77.5	77.9	78.3	78.7	79.0
4000	67.6	68.4	69.1	69.8	70.4	71.1	71.7	72.3	72.8	73.4	73.9	74.4	74.9	75.4	75.8	76.3	76.7	77.1	77.5	77.9	78.3
4200	66.8	67.5	68.3	68.9	69.6	70.3	70.9	71.5	72.0	72.6	73.1	73.6	74.1	74.6	75.1	75.5	75.9	76.4	76.8	77.2	77.5
4400	65.9	66.7	67.4	68.1	68.8	69.4	70.1	70.7	71.2	71.8	72.3	72.8	73.3	73.8	74.3	74.7	75.2	75.6	76.0	76.4	76.8
4600	65.1	65.8	66.6	67.3	68.0	68.6	69.2	69.8	70.4	71.0	71.5	72.0	72.5	73.0	73.5	74.0	74.4	74.8	75.2	75.6	76.0
4800	64.2	65.0	65.7	66.4	67.1	67.8	68.4	69.0	69.6	70.2	70.7	71.2	71.7	72.2	72.7	73.2	73.6	74.0	74.5	74.9	75.3
5000	63.4	64.2	64.9	65.6	66.3	66.9	67.6	68.2	68.8	69.3	69.9	70.4	70.9	71.4	71.9	72.4	72.8	73.2	73.7	74.1	74.5
5200	62.5	63.3	64.1	64.8	65.5	66.1	66.8	67.4	68.0	68.5	69.1	69.6	70.1	70.6	71.1	71.6	72.0	72.5	72.9	73.3	73.7
5400	61.7	62.5	63.2	63.9	64.6	65.3	65.9	66.5	67.1	67.7	68.3	68.8	69.3	69.8	70.3	70.8	71.2	71.7	72.1	72.5	72.9
5600	60.9	61.6	62.4	63.1	63.8	64.5	65.1	65.7	66.3	66.9	67.4	68.0	68.5	69.0	69.5	70.0	70.4	70.9	71.3	71.7	72.1
5800	60.0	60.8	61.5	62.3	63.0	63.6	64.3	64.9	65.5	66.1	66.6	67.2	67.7	68.2	68.7	69.2	69.6	70.1	70.5	70.9	71.3
6000	59.2	60.0	60.7	61.4	62.1	62.8	63.4	64.1	64.7	65.2	65.8	66.3	66.9	67.4	67.9	68.4	68.8	69.3	69.7	70.1	70.5

(Table continued on next page)

TABLE I—MECHANICAL EFFICIENCY OF SPARK IGNITION ENGINES, % (CONTINUED)

	bmep, kPa																				
	689	703	717	731	745	758	772	786	800	813	827	841	855	869	882	896	910	924	938	951	965
	bmep, lb/in.²																				
rpm	100	102	104	106	108	110	112	114	116	118	120	122	124	126	128	130	132	134	136	138	140
800	88.4	88.7	89.0	89.3	89.5	89.8	90.0	90.2	90.5	90.7	90.9	91.1	91.3	91.5	91.7	91.9	92.1	92.2	92.4	92.6	92.7
1000	87.9	88.2	88.5	88.8	89.0	89.3	89.5	89.8	90.0	90.2	90.5	90.7	90.9	91.1	91.3	91.5	91.6	91.8	92.0	92.2	92.3
1200	87.4	87.7	88.0	88.3	88.5	88.8	89.1	89.3	89.5	89.8	90.0	90.2	90.4	90.6	90.8	91.0	91.2	91.4	91.6	91.7	91.9
1400	86.9	87.2	87.5	87.8	88.0	88.3	88.6	88.8	89.0	89.3	89.5	89.7	89.9	90.1	90.4	90.5	90.7	90.9	91.1	91.3	91.5
1600	86.3	86.6	86.9	87.2	87.5	87.8	88.0	88.3	88.5	88.8	89.0	89.2	89.4	89.7	89.9	90.1	90.3	90.5	90.6	90.8	91.0
1800	85.8	86.1	86.4	86.7	86.9	87.2	87.5	87.7	88.0	88.2	88.5	88.7	88.9	89.1	89.3	89.6	89.8	89.9	90.1	90.3	90.5
2000	85.2	85.5	85.8	86.1	86.4	86.6	86.9	87.2	87.4	87.7	87.9	88.1	88.4	88.6	88.8	89.0	89.2	89.4	89.6	89.8	90.0
2200	84.5	84.9	85.2	85.5	85.8	86.0	86.3	86.6	86.8	87.1	87.3	87.6	87.8	88.0	88.3	88.5	88.7	88.9	89.1	89.3	89.5
2400	83.9	84.2	84.5	84.8	85.1	85.4	85.7	86.0	86.3	86.5	86.8	87.0	87.2	87.5	87.7	87.9	88.1	88.3	88.5	88.7	88.9
2600	83.2	83.6	83.9	84.2	84.5	84.8	85.1	85.4	85.6	85.9	86.2	86.4	86.6	86.9	87.1	87.3	87.5	87.8	88.0	88.2	88.4
2800	82.6	82.9	83.2	83.6	83.9	84.2	84.5	84.7	85.0	85.3	85.5	85.8	86.0	86.3	86.5	86.7	86.9	87.2	87.4	87.6	87.8
3000	81.9	82.2	82.6	82.9	83.2	83.5	83.8	84.1	84.4	84.6	84.9	85.2	85.4	85.6	85.9	86.1	86.3	86.6	86.8	87.0	87.2
3200	81.2	81.5	81.9	82.2	82.5	82.8	83.1	83.4	83.7	84.0	84.2	84.5	84.8	85.0	85.2	85.5	85.7	85.9	86.2	86.4	86.6
3400	80.5	80.8	81.2	81.5	81.8	82.1	82.5	82.7	83.0	83.3	83.6	83.8	84.1	84.4	84.6	84.8	85.1	85.3	85.5	85.7	85.9
3600	79.8	80.1	80.5	80.8	81.1	81.5	81.8	82.1	82.3	82.6	82.9	83.2	83.4	83.7	83.9	84.2	84.4	84.6	84.9	85.1	85.3
3800	79.0	79.4	79.8	80.1	80.4	80.7	81.1	81.4	81.7	81.9	82.2	82.5	82.8	83.0	83.3	83.5	83.7	84.0	84.2	84.4	84.7
4000	78.3	78.7	79.0	79.4	79.7	80.0	80.3	80.6	80.9	81.2	81.5	81.8	82.1	82.3	82.6	82.8	83.1	83.3	83.5	83.8	84.0
4200	77.5	77.9	78.3	78.6	79.0	79.3	79.6	79.9	80.2	80.5	80.8	81.1	81.4	81.6	81.9	82.1	82.4	82.6	82.9	83.1	83.3
4400	76.8	77.2	77.5	77.9	78.2	78.6	78.9	79.2	79.5	79.8	80.1	80.4	80.6	80.9	81.2	81.4	81.7	81.9	82.2	82.4	82.6
4600	76.0	76.4	76.8	77.1	77.5	77.8	78.1	78.5	78.8	79.1	79.4	79.6	79.9	80.2	80.5	80.7	81.0	81.2	81.5	81.7	81.9
4800	75.3	75.6	76.0	76.4	76.7	77.1	77.4	77.7	78.0	78.3	78.6	78.9	79.2	79.5	79.7	80.0	80.3	80.5	80.8	81.0	81.2
5000	74.5	74.9	75.2	75.6	76.0	76.3	76.6	77.0	77.3	77.6	77.8	78.2	78.5	78.7	79.0	79.3	79.5	79.8	80.0	80.3	80.5
5200	73.7	74.1	74.5	74.8	75.2	75.5	75.9	76.2	76.5	76.8	77.1	77.4	77.7	78.0	78.3	78.5	78.8	79.1	79.3	79.6	79.8
5400	72.9	73.3	73.7	74.1	74.4	74.8	75.1	75.4	75.8	76.1	76.4	76.7	77.0	77.3	77.5	77.8	78.1	78.3	78.6	78.8	79.1
5600	72.1	72.5	72.9	73.3	73.6	74.0	74.3	74.7	75.0	75.3	75.6	75.9	76.2	76.5	76.8	77.1	77.3	77.6	77.8	78.1	78.3
5800	71.3	71.7	72.1	72.5	72.9	73.2	73.6	73.9	74.2	74.5	74.9	75.2	75.5	75.7	76.0	76.3	76.6	76.8	77.1	77.4	77.6
6000	70.5	70.9	71.3	71.7	72.1	72.4	72.8	73.1	73.5	73.8	74.1	74.4	74.7	75.0	75.3	75.6	75.8	76.1	76.4	76.6	76.9

4.5.3 Diesel Engines

4.5.3.1 *Correction Factor*

$$C_D = \frac{B_d^*}{B_{dt}} \cdot \left(\frac{t_t + A}{t^* + A}\right)^{0.7}$$

4.5.3.2 *Friction*—If the preferred hot motored friction is not used, Table 2 may be used to approximate diesel engine friction for use in this code. If it is not used, the following equations shall be used to calculate mechanical efficiency and friction power:

When $bmep_t$ is in lb/in.²:

$$n = \frac{100}{1 + \frac{z}{bmep_t}}$$

When $bmep_t$ is in kPa:

$$n = \frac{100}{1 + \frac{6.89z}{bmep_t}}$$

In both equations:

$$z = 20.1893 - 3.75948\left(\frac{N}{1000}\right) + 3.33129\left(\frac{N}{1000}\right)^2$$

4.5.3.3 *Correction Calculation*—Since the diesel engine operates at a set fuel rate, the correction factor defined in paragraph 4.5.3.1 shall be applied in conjunction with the following procedure.

At test atmospheric conditions, engine power and fuel rate shall be measured and recorded at three fuel rate settings at the same engine speed. One test point should be at the desired fuel setting. When the test air density is less than standard density, the other two points should be at approximately 5% and 10% lower fuel rates. When the test air density is greater than standard density, the other two points should be at approximately 5% and 10% higher fuel rates for best accuracy. When practical considerations, such as limited pump delivery, prevent use of the higher rates, points at lower fuel rates may be used, but some accuracy will be lost due to extrapolation rather than interpolation of data. Engine friction shall be recorded as friction power at the rated fuel setting for naturally aspirated engines and as mechanical efficiency at each fuel setting for turbocharged engines. Calculate $isfc_t$ at each test point (see paragraph 4.4.3) and plot versus fuel rate as shown in Fig. 1.

Find corrected indicated specific fuel consumption ($isfc_c$) on Fig. 1 at F':

$$F' = \frac{F_r}{C_D}$$

Calculate corrected bp for naturally aspirated engines by

$$bp_c = \frac{F_r}{isfc_c} - fp_t$$

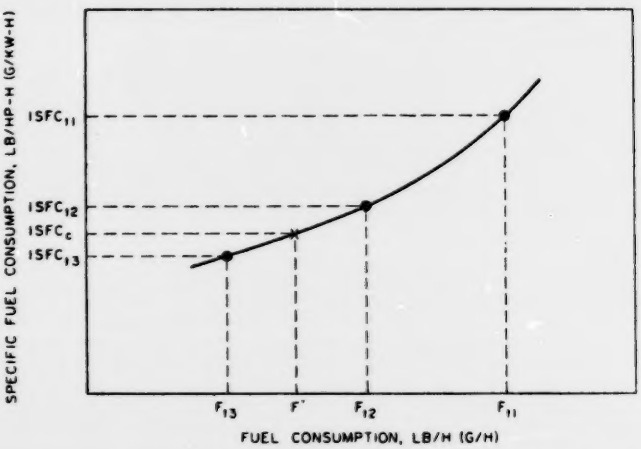


FIG. 1—METHOD OF ESTABLISHING FUEL CONSUMPTION FOR POWER CORRECTION FOR DIESEL ENGINES

or for turbocharged engines by

$$bp_c = \frac{F_r}{isfc_c} \cdot \left(\frac{n}{100}\right)$$

where mechanical efficiency (n) may be obtained from hot motored test data or the formula in paragraph 4.5.3.2.

Abbreviated correction procedures based upon this method will be considered acceptable if they result in corrected values identical to those obtained by this three-point procedure.

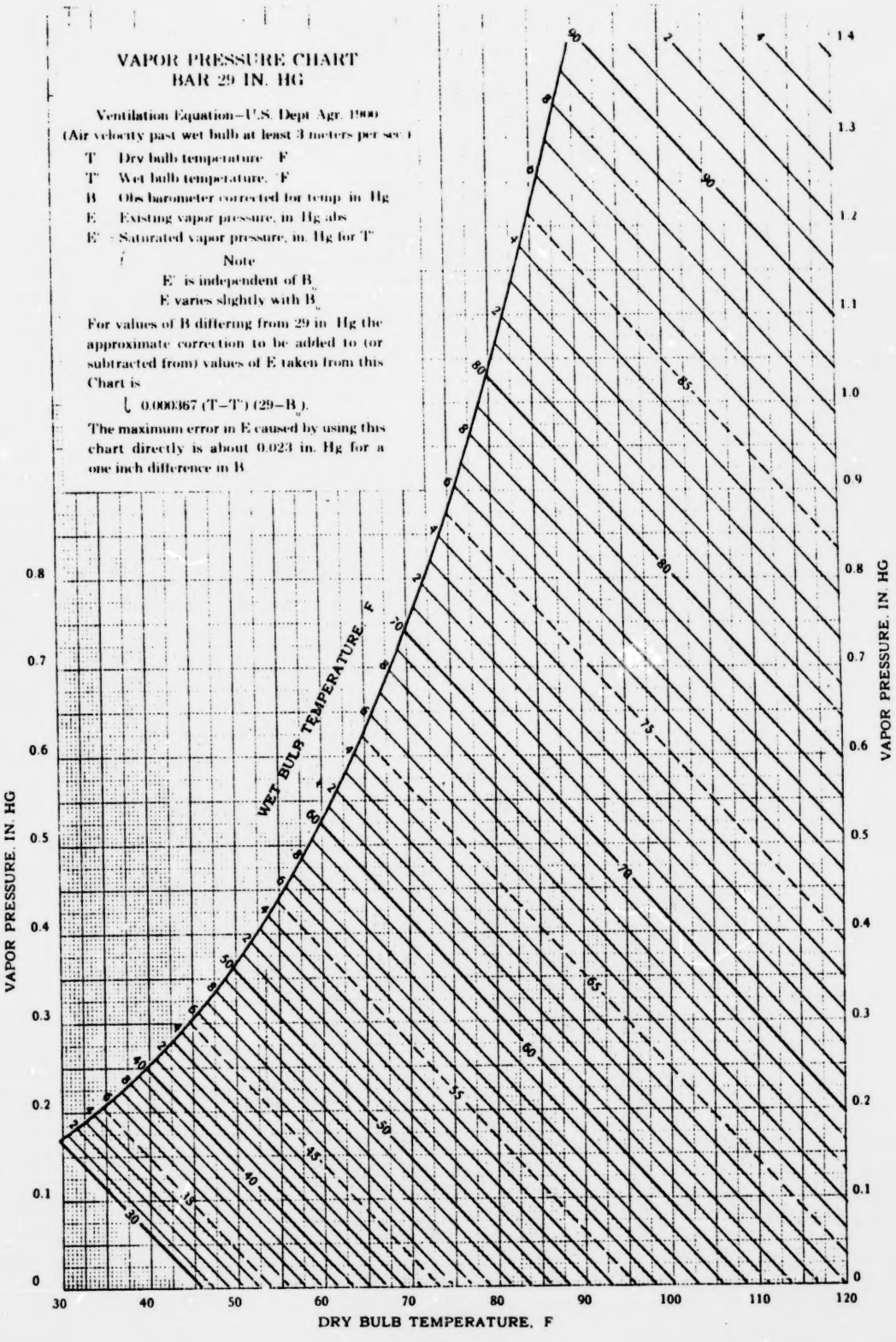
$$\text{Corrected brake torque, } T = \frac{G}{N} \cdot bp_c$$

$$\text{Corrected brake mean effective pressure, } bmep_c = \frac{E \cdot a}{D \cdot N} \cdot bp_c$$

Fuel consumption—Fuel consumption at standard conditions is, by definition, the same as at test conditions.

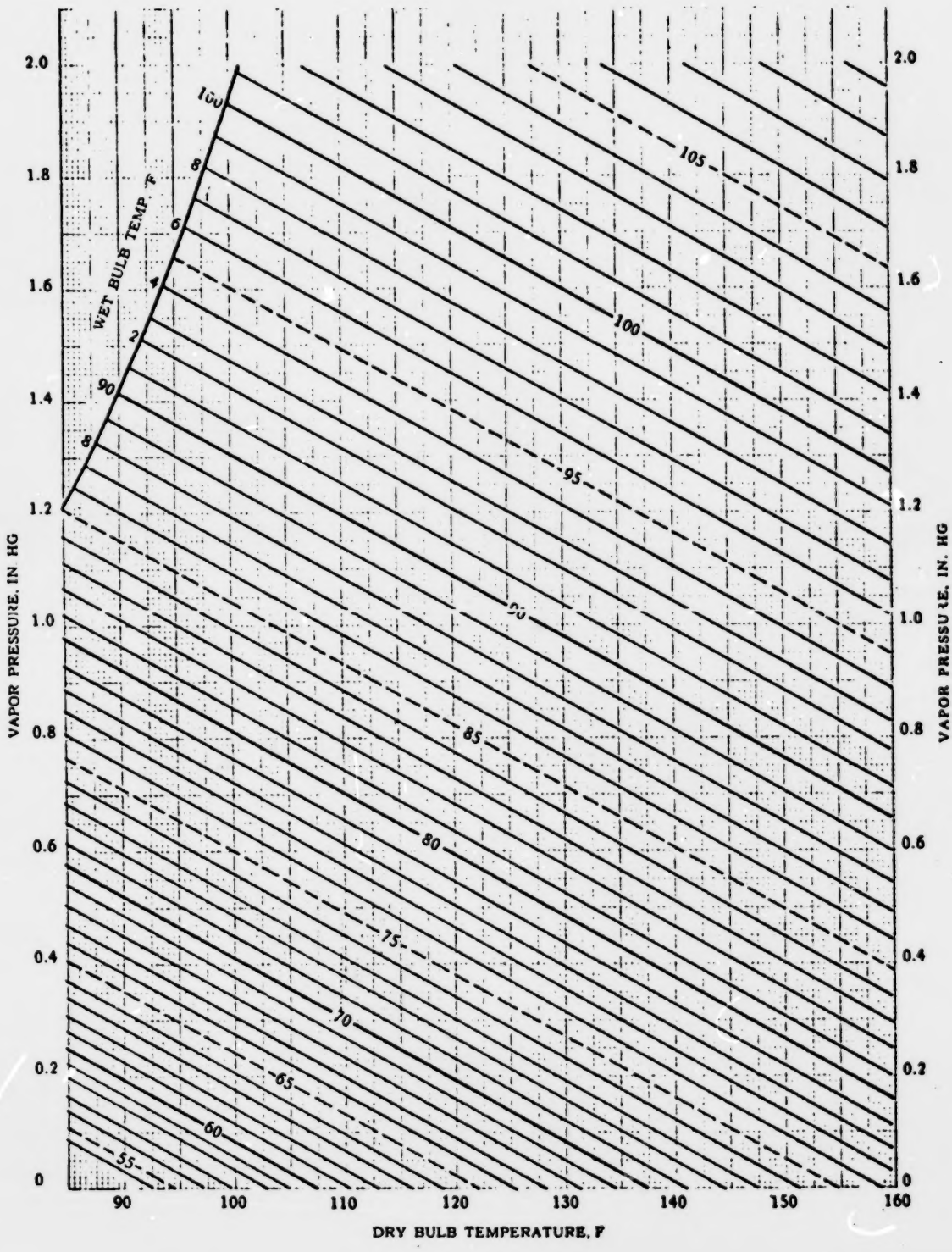
$$F_c = F_t$$

$$\text{Brake specific fuel consumption, } bsfc_c = \frac{F_c}{bp_c}$$


VAPOR PRESSURE CHART
BAR 29 IN. HG
Ventilation Equation—U.S. Dept Agr. 1909
(Air velocity past wet bulb at least 3 meters per sec.)
T Dry bulb temperature °F
T' Wet bulb temperature °F
B Obs barometer corrected for temp in Hg
E Existing vapor pressure, in Hg abs
E' = Saturated vapor pressure, in. Hg for T'
Note
E' is independent of B
E varies slightly with B
For values of B differing from 29 in Hg the approximate correction to be added to (or subtracted from) values of E taken from this Chart is
0.000367 (T−T') (29−B).
The maximum error in E caused by using this chart directly is about 0.023 in. Hg for a one inch difference in B
WET BULB TEMPERATURE, F
VAPOR PRESSURE, IN. HG
VAPOR PRESSURE, IN. HG
DRY BULB TEMPERATURE, F
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
30
40
50
60
70
80
90
100
110
120

VAPOR PRESSURE CHART—BAR 29 IN. HG

(Continued)



APPENDIX 2

Calculation of Air-Fuel Ratio from Exhaust Gas Constituents [1,2,3]

The combustion reaction for a hydrocarbon fuel with air may be expressed as:

$$CHy + (n)O_2 + (3.76n)N_2 \rightarrow (a)CO_2 + (1-a-6c)\ CO + (b)H_2O + (c)C_6H_{14} + (d)NO + (\frac{y}{2} - b - 7c)H_2 + (n-a-\frac{1-a-6c}{2} - \frac{b}{2} - \frac{d}{2})O_2 + (3.76\ n - \frac{d}{2})N_2 \quad (1)$$

for one atom of carbon, in which:

( ) = mol of constituents for 1 mol of fuel CH_y (bracketed coefficient)

y = fuel atomic H/C ratio

C_6H_{14} = unburned hydrocarbon, reported as hexan

For a nondispersive infrared (NDIR) analyzer, the term (HC) can be multiplied by a factor of 1.8, to account for the lack of response to certain exhaust HC species (for flame ionization detectors - FID - the factor is 1.0).

Defining a "fuel conversion factor" N:

$$N = \frac{\text{mol exhaust}}{\text{mol fuel}} = \frac{100}{6(HC)+(CO)+(CO_2)} \quad (2)$$

( ) = molar percent (bracketed species)

expressed in [%], and summing the mols of products from eq. (1):

$$N = a+(1-a-6c)+w+c+d(\frac{y}{2}-b-7c)+(n-a-\frac{1-a-6c}{2}-\frac{b}{2}-\frac{d}{2})+(3.76\ n-\frac{d}{2}) \quad (3)$$

in which mols of water produced b are replaced by w, mols of water at analyzer, following any condensation. With no condensation, w = b.

$$N = 4.76\ n - 6c + \frac{1-a-6c-3b+y}{2} + w \tag{4}$$

For the reactants in eq. (1):

$$\frac{\text{mol air}}{\text{mol fuel}} = n+3.76\ n = 4.76\ n \tag{5}$$

combining eq. (4) and (5)

$$\frac{\text{mol air}}{\text{mol air}} = N+6c-\frac{1-a-6c}{2} + \frac{3b}{2} - \frac{y}{2} - w \tag{6}$$

and because:

$$\frac{\text{mol X}}{\text{mol fuel}} = \frac{\text{mol X}}{\text{mol exhaust}} \cdot \frac{\text{mol exhaust}}{\text{mol fuel}} = \frac{(X)}{100} \cdot N \tag{7}$$

Eq. (6) becomes:

$$\frac{\text{mol air}}{\text{mol fuel}} = N+\frac{6(HC)}{100} \cdot N-\frac{(CO)}{200} \cdot N+\frac{3(H_2O)}{200}\ N- \\ - \frac{y}{2} - \frac{(H_2O)a}{100} \cdot N \tag{8}$$

where $(H_2O)_a$ is water concentration (percent) at analyzers

$$\frac{A}{F} = \frac{\text{g air}}{\text{g fuel}} = \frac{\text{mol air}}{\text{mol fuel}} \cdot \frac{\text{M air}}{\text{M fuel}} \tag{9}$$

where M refers to molecular weight

$$\frac{A}{F} = \frac{\text{M air}}{\text{M fuel}} \left\{ N + \frac{N}{100} \left[6(HC) - \frac{(CO)}{2} + \frac{3(H_2O)}{2} - (H_2O)_a \right] - \frac{y}{2} \right\} \tag{10}$$

Assuming a fixed value for the water-gas equilibrium

$$k = \frac{(CO)(H_2O)}{(CO_2)(H_2)} = 3.8 \tag{11}$$

and with

$$(H_2) = \left(\frac{y}{2} - b - 7c\right) \frac{100}{N} = \frac{y}{2} \cdot \frac{100}{N} - (H_2O) - 7\,(HC) \tag{12}$$

$$(H_2O) = \frac{\frac{y}{2} \cdot \frac{100}{N} - 7(HC)}{\frac{(CO)}{k(CO_2)} + 1} \tag{13}$$

From eq. (10) and (13) a <u>carbon balance</u> air-fuel ratio can be expressed as:

$$\frac{A}{F} = \frac{M\ air}{M\ fuel}\left[\frac{100+6(HC)-\frac{(CO)}{2}+\frac{3(H_2O)}{2}-(H_2O)_a}{6(HC)+(CO)+(CO_2)} - \frac{y}{2}\right] \tag{14}$$

in which:

$$(H_2O) = \frac{y[(CO_2)+(CO)]}{2\left[\frac{(CO)}{3.8(CO_2)}+1\right]} \tag{15}$$

Molecular weights:

M air = 28.96

M fuel = Mc + y M_H = 12.01 + 1.008 y

An <u>oxygen balance</u> independent of the amount of water and diluents is also derived:

$$n = a + \frac{1-a-6c}{2} + \frac{b}{2} + \frac{d}{2} + \left(n-a-\frac{1-a-6c}{2}-\frac{b}{2}-\frac{d}{2}\right) \tag{16}$$

$$n = \frac{N}{100}\left[(CO_2) + \frac{(CO)}{2} + \frac{(H_2O)}{2} + \frac{(NO)}{2} + (O_2)\right] \tag{17}$$

$$\frac{A}{F} = 4.76\ n\ \frac{M\ air}{M\ fuel} \tag{18}$$

$$\frac{A}{F} = 4.76 \frac{M\ air}{M\ fuel} \frac{N}{100} \left[(CO_2) + \frac{(CO)}{2} + \frac{(H_2O)}{2} + \frac{(NO)}{2} + (O_2)\right] \quad (19)$$

or

$$\frac{A}{F} = 4.76 \frac{M\ air}{M\ fuel} \left[\frac{(CO_2)+\frac{(CO)}{2}+\frac{(H_2O)}{2}+\frac{(NO)}{2}+(O_2)}{6(HC) + (CO) + (CO_2)}\right] \quad (20)$$

In equations (14) or (20), the molar concentration (HC) is multiplied by 1.8 if the analyzer is nondispersive infrared.

The oxygen balance computation of A/F ratio for 31 samples of exhaust analysis quoted in Table A-1 of Reference [1], resulted in an average error of +0.2352 comparative to measured values of air and fuel mass flows.

For propane (C_3H_8):

$y = \frac{H}{C} = \frac{8}{3} = 2.6667$ and M fuel = $12.01 + 1.008 \times 2.6667 = 14.698$

The values in Paragraph 6 are calculated according to eq. (20) and (15).

BIBLIOGRAPHY

1. Stivender, D.L., "Development of a Fuel - Based Mass Emission Measurement Procedure", SAE Paper 710604.

2. Stivender, D.L., Kim, Y.G., "Dynamic Computer Techniques for Vehicle Emission Development", SAE Paper 720211.

3. GM Test Code, VI Edition, 1975, pp. 170; "Air-Fuel Ratio Determination from Exhaust Gas Constituents".

APPENDIX 3

Classification of Tested LPG Carburetion Systems

(1 = best)

Parameter	Load [%]	Speed [rpm]	Carburetion system							
			BEAM	A.F.S.	ALGAS	CENTURY	C.F.S	FUELCON	C.K.	IMPCO
Fuel economy	100	1300	5	1	3	8	6	2	7	4
		1800	8	1	5	4	6	1	7	3
		2400	8	1	5	2	4	6	7	3
		3000	8	1	3	2	4	7	5	6
		3600	8	3	1	3	2	7	5	6
	66	1300	3	5	4	1	6	8	7	2
		1800	3	6	5	1	4	8	7	2
		2400	2	4	3	1	8	6	6	5
		3000	3	4	5	2	7	8	6	1
		3600	4	6	5	2	7	8	3	1
	33	1300	4	6	5	1	2	8	7	3
		1800	5	3	3	1	6	7	8	2
		2400	3	5	4	2	8	7	6	1
		3000	3	5	4	2	8	7	6	1
		3600	5	7	6	1	8	2	4	3

Parameter	Load [%]	Speed [rpm]	Carburetion system							
			BEAM	A.F.S.	ALGAS	CENTURY	C.F.S.	FUELCON	C.K.	IMPCO
Fuel economy (cont.)	≈10	1300	1	2	3	6	4	8	5	7
		1800	1	4	3	2	5	8	6	7
		2400	1	6	3	4	5	8	7	2
		3000	2	5	3	4	7	8	6	1
		3600	5	7	6	1	8	4	3	2
	Average		4.10	4.10	3.95	2.50	5.75	6.40	5.90	3.10
Emissions (HC/CO/NO)	100	1300	7 6 4	1 1 8	8 5 3	4 8 1	5 7 2	6 4 6	3 3 7	2 2 5
		1800	7 8 2	2 2 8	8 6 3	4 3 7	6 7 1	5 4 6	3 5 5	1 1 4
		2400	6 7 3	2 1 8	7 6 5	5 4 6	4 3 7	8 8 1	3 4 4	1 2 2
		3000	7 7 3	2 2 8	5 3 7	6 5 5	1 1 6	8 7 2	2 4 4	4 6 1
		3600	6 7 5	2 2 7	4 3 8	7 5 3	1 1 6	8 8 1	3 4 4	5 6 2
	66	1300	5 4 6	4 2 7	3 6 8	2 3 2	7 7 4	8 8 1	6 5 5	1 1 3
		1800	3 3 6	5 3 7	4 2 8	1 3 1	8 8 2	7 7 4	6 6 5	2 1 3
		2400	5 2 6	3 2 7	4 2 8	2 5 2	8 8 3	7 7 4	6 6 5	1 1 1
		3000	5 2 6	4 5 7	3 2 8	2 4 4	7 7 3	8 8 1	6 6 5	1 1 2
		3600	5 2 6	3 5 8	2 2 7	3 4 5	7 6 4	8 8 1	6 7 3	1 1 2

Parameter	Load [%]	Speed [rpm]	Carburetion system							
			BEAM	A.F.S.	ALGAS	CENTURY	C.F.S.	FUELCON	C.K.	IMPCO
Emissions (HC/CO/NO) (cont.)	33	1300	5 3 5	3 5 8	5 7 7	2 3 2	3 2 3	8 8 1	7 6 6	1 1 4
		1800	6 2 4	4 5 8	2 3 7	3 3 1	4 5 6	8 8 2	7 7 5	1 1 3
		2400	2 2 5	4 5 7	2 2 8	6 2 1	7 8 3	8 5 2	5 7 6	1 1 4
		3000	4 2 6	2 5 8	3 4 7	5 3 1	8 8 3	7 7 4	6 6 5	1 1 2
		3600	5 2 6	2 5 8	2 2 7	4 4 2	8 8 3	7 7 4	6 6 5	1 1 1
	≈10	1300	7 4 1	3 4 5	4 6 4	6 7 6	5 3 2	8 8 3	2 2 8	1 1 7
		1800	6 4 3	3 7 7	4 4 5	2 4 6	7 2 1	8 2 2	5 8 8	1 1 4
		2400	5 4 3	2 6 8	4 4 6	7 2 1	2 2 5	8 8 4	6 7 7	1 1 2
		3000	4 2 5	2 5 8	2 4 7	6 2 1	7 7 4	8 8 3	5 6 6	1 1 2
		3600	4 3 5	2 5 8	3 2 7	6 3 1	8 8 3	7 7 4	5 6 6	1 1 2
Average			5.20 3.80 4.50	2.75 3.85 7.50	3.95 3.75 6.50	4.15 3.85 2.90	5.65 5.40 3.55	7.50 6.85 2.80	4.90 5.55 5.45	1.45 1.60 2.80